Posture Development and Vocalization Production in Infants at Heightened Risk for Autism Spectrum Disorder

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POSTURE DEVELOPMENT AND VOCALIZATION PRODUCTION IN INFANTS AT HEIGHTENED RISK FOR AUTISM SPECTRUM DISORDER

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During the first 14 months of life, typically-developing (TD) infants demonstrate rapid advances in posture and vocal development. There is a striking synchronization in the emergence of important milestones in these two domains (e.g., Oller, 1980; Piper & Darrah, 1994). For example, between the ages of 6 and 8 months, TD infants begin to sit independently without relying on external support for balance. Around this same time, they begin to produce syllabic vocalizations, which are defined as consonant-vowel (CV) sounds that are characteristic of babbling (e.g., [ba]; Oller, 2000). Between approximately 10 and 12 months, most TD infants can stand unsupported and say their first words, and by the time they reach 14 months they are walking long distances and producing nearly 20 words (Fenson et al., 1994).

Although posture and vocal development were once considered unrelated, there is mounting evidence demonstrating a developmental pathway linking behaviors in these domains (see Iverson, 2010, for a review). Specifically, the emergence of new postures as well as increased postural control (i.e., the ability to maintain a stable posture over time) dramatically change infants' experiences with objects, people, and their own bodies in ways that are relevant not only for motor development (e.g., reaching and manual exploration; Rochat & Goubet, 1995), but for development in other domains (e.g., vocalizations; Yingling, 1981). One implication of this framework is that even seemingly small disruptions in posture development can have cascading effects that lead to delays outside of the motor domain (see Iverson, 2010, for additional discussion).

Keywords: autism spectrum disorders, posture development, and vocalization development

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1.0 INTRODUCTION

While social and communicative impairments are the defining feature of autism spectrum disorder (ASD; American Psychiatric Association, 2013), various aspects of postural and vocal behavior appear to be disrupted in children across the autism spectrum and across a full range of cognitive functioning (e.g., Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Sheinkopf, Mundy, Oller, & Steffens, 2000; Wetherby, Watt, Morgan, & Shumway, 2007). With the goal of early identification of ASD, several ongoing studies have begun to examine prospectively the very early development of infants who are at heightened risk (HR) for ASD by virtue of having an affected older sibling (ASD recurrence risk is 18.7%; Ozonoff et al., 2011). Surprisingly, there has been a relative lack of research with HR infants focused on posture and vocal behaviors and therefore little is known about the emergence and course of early development in these domains (Jones, Gliga, Bedford, Charman, & Johnson, 2013). Thus, one goal of the proposed research is to describe developmental trajectories for posture and vocalizations in HR infants and a group of comparison infants with low ASD risk (Low Risk; LR) from 6 to 14 months of age. To determine whether patterns of delay are specific to ASD, trajectories for HR infants later diagnosed with ASD will be compared to those of HR infants with language delay, HR infants with no symptoms, and a comparison group of LR infants with no family history of ASD.

In addition, one of the most consistent findings from prospective research has been that as a group, HR infants, even those who do not receive an ASD diagnosis, are extremely variable in their developmental trajectories (Rogers, 2009), with a large number of HR infants exhibiting delays across multiple behavioral domains (e.g., motor, vocalizations, language). Thus, studies of HR infants not only have the potential to identify early indices of a later ASD diagnosis, but they can also reveal important information about very early developmental processes in this particularly variable population. Since the emergence of unsupported sitting has been linked to the development of syllabic vocalizations in TD infants (Yingling, 1981), research with populations that exhibit delayed development in one or both of these areas has the potential to shed light on underlying mechanisms of development and set the stage for future intervention research. Therefore, a second goal of the current study is to provide an initial examination of the relationship between the emergence of unsupported sitting and the development of syllabic vocalizations in HR infants.

1.1 POSTURE DEVELOPMENT

1.1.1 Typical Development

During the first 14 months, TD infants progress from postures in which the entire body is fully supported by a surface to postures that require greater strength, muscle coordination, and balance (e.g., unsupported sitting, all fours, standing). Because newborns' neck muscles are weak and body dimensions are extremely top heavy, with a head that is very large relative to the torso and limbs (e.g., Bly, 1994; Ounsted, Moar, & Scott, 1986; Palmer, 1944), overcoming the force of gravity is particularly challenging. Thus, in the first few months, infants' posture repertoires are limited to prone (i.e., lying on the stomach) and supine (i.e., lying on the back; Piper & Darrah, 1994)

The development of sitting represents one of the initial successes for infants in overcoming the force of gravity. The first step in the developmental progression toward sitting is the ability to stabilize the head between the shoulders (Bly, 1994). Next, infants must gain sufficient muscular control of the trunk so that they do not topple over due to insufficient hip or back support (e.g., Harbourne & Stergiou, 2003). By approximately 5 months of age, TD infants can sit by balancing on their bottoms and propping themselves up with their hands resting on the floor (i.e., Infant Sustained Sitting; Piper & Darrah, 1994). With increased practice, infants become better able to integrate vestibular and proprioceptive information continuously with ongoing motor activity to control postural sway (i.e., fluctuation in movement that may stem from rapid postural adjustment while trying to maintain a static posture) in the sitting position. It is at around 6 months that TD infants begin to sit unsupported with their arms free to reach for and manipulate objects (Piper & Darrah, 1994).

While unsupported sitting is dependent on sufficient muscular control of the neck and torso to stabilize the head and upper body, postures such as all-fours and standing require greater balance and limb strength. By 7 months of age, on average, TD infants have sufficient arm strength and balance to support themselves on their hands and knees with their hips off of the floor (Piper & Darrah, 1994). From 8 to 9 months, TD infants start to use furniture to pull themselves upright into an infant sustained standing posture, and by 12 months most TD infants can maintain balance without any external support in the unsupported stand posture (Frankenburg & Dodds, 1967; Piper & Darrah, 1994).

1.1.2 Autism Spectrum Disorder

Because it is difficult to diagnose ASD reliably prior to 30 months of age (e.g., Turner & Stone, 2007), there is a dearth of research examining the development of posture in infancy and early toddlerhood. Nevertheless, deficits in postural control are widespread among older children and adults across the autism spectrum and full range of cognitive functioning (see Bhat, Landa, & Galloway, 2011 for a review; see Fournier, Hass, et al., 2010 for a meta-analysis). For example, on standardized motor assessments, children with ASD exhibit a significant impairment in the ability to sustain balance for an extended period of time (e.g., Ghaziuddin, Butler, Tsai, & Ghaziuddin, 1994; Green et al., 2002; Green et al., 2009; Jansiewicz et al., 2006; Noterdaeme, Mildenberger, Minow, & Amorosa, 2002). Other studies utilizing force platform technology to quantify postural sway in individuals with ASD have reported that relative to TD comparison groups, individuals with ASD tend to exhibit greater postural sway during quiet stance (e.g., Fournier, Kimberg, et al., 2010; Minshew, Sung, Jones, & Furman, 2004; Molloy, Dietrich, & Bhattacharya, 2003; Travers, Powell, Klinger, & Klinger, 2013).

Evidence of difficulties with postural control in older children and adults with ASD has led to the investigation of infants eventually diagnosed with the disorder to determine whether or not delays and/or atypicalities in posture can be detected in infancy. In one of the first retrospective home video studies, Adrien et al. (1993) found that compared to TD infants, infants with ASD exhibited abnormally low muscle tone and were more frequently observed in asymmetrical lying and sitting positions during the first year, observations that may be interpreted as early signs of neurological disruption.

More recent studies have also pointed to delayed development of specific postural milestones among infants eventually diagnosed with ASD. For example, Ozonoff et al. (2008)

found that according to retrospective parent report, infants later diagnosed with ASD were older at the onsets of unsupported sitting (M_{ASD} = 6.80, M_{TD} = 5.17), crawling (M_{ASD} = 8.31, M_{TD} = 6.89), and walking (M_{ASD} = 13.44, M_{TD} = 10.90) compared to TD infants. In addition, analyses of retrospective home videos revealed that infants later diagnosed with ASD did not exhibit mature walking (i.e., walk with heel strike and narrow base of support) until 18 months of age, which was 3 months later than the TD group. These findings are supported by a recent study from the Danish National Birth Cohort, in which investigators examined prospectively collected interviews from mothers of 76,441 infants (720 with an ASD diagnosis) about their infants' development from 6 to 18 months of age (Lemcke, Juul, Parner, Lauritsen, & Thorsen, 2013). They found that relative to TD children, significantly more children who were eventually diagnosed with ASD could not sit up straight when held on their parents' laps at 6 months. In addition, children with ASD were significantly older than TD children when they achieved the unsupported sitting (M_{ASD} = 6.9 months, M_{TD} = 6.5 months) and walking (M_{ASD} = 13.7 months, M_{TD} = 12.6 months) milestones.

1.1.3 Infants at Heightened Risk for ASD

Although prospective longitudinal designs with general population samples is an ideal method for identifying early diagnostic markers of ASD because they involve a sample of children who are representative of the general population, they are not practically feasible given that the prevalence of ASD in the US is 1 in 68 children (Baio, 2014). Thus, even if a researcher followed over 600 infants, the number of children who would receive an eventual ASD diagnosis would be fewer than 10. This has led to the study of HR infants, for whom risk for ASD is enhanced because they have an older sibling with the disorder. Relative to the ASD prevalence rate in the general population, that for HR infants is much greater (approximately 1 in 6 children; Ozonoff et al., 2011). In general, infant sibling studies involve following samples of HR infants and comparison LR infants prospectively and longitudinally from infancy through early childhood to an age when a reliable diagnosis of ASD is possible.

To date, a small number of studies of HR infants have focused on motor development in the first 18 months. Nevertheless, this limited body of research provides suggestive evidence of very early posture delays, with the most pronounced delays observed among those who later receive an ASD diagnosis (e.g., Leonard et al., 2013; Nickel, Thatcher, Keller, Wozniak, & Iverson, 2013). Three studies have used standardized assessments to examine posture development in HR infants. In the first of these, Bhat, Galloway, and Landa (2012), found that relative to LR infants, HR infants scored significantly lower on the Alberta Infant Motor Scale (AIMS; Piper & Darrah, 1994) at both 3 and 6 months of age. Furthermore, the percentage of infants who were considered low motor performers (i.e., a percentile rank between 0 and 25th; Van Haastert, De Vries, Helders, & Jongmans, 2006) was significantly higher for HR infants (78% at 3 months, 50% at 6 months) than for LR infants (33% at 3 months, 8.3% at 6 months). However, because this study did not have diagnostic outcome information, it is unclear whether differences between groups can be accounted for by those HR infants who go on to receive an ASD diagnosis.

Leonard et al. (2013) also found that compared to LR infants, HR infants as a group exhibited posture delays; and this result was not specific to infants eventually diagnosed with ASD. Specifically, the Gross Motor subscale from Mullen Scales of Early Learning (MSEL; Mullen, 1995) was used to evaluate posture development in HR infants at 7, 14, and 24 months. Although the MSEL is not specifically a tool for assessing posture development, the Gross Motor subscale includes items such as the ability to sit, stand, and squat. Cross-sectional analyses of standardized scores (M = 100, SD = 15) indicated that relative to LR infants, HR infants as a group had significantly lower scores at 7 (M_{LR} = 50.17, M_{HR} = 45.40), and 24 (M_{LR} = 59.89, M_{HR} = 45.19) months, but not at 14 months (M_{LR} = 51.04, M_{HR} = 46.26). Although HR infants with ASD scored slightly lower than HR infants without ASD at each of the age points, there were no significant differences between these groups.

Finally, Landa and Garrett-Mayer (2006) used the Gross Motor subscale of the MSEL to examine differences between HR and LR outcome groups (i.e., TD, ASD, and LD) at 6, 14, and 24 months. Cross-sectional analyses using raw scores revealed that there were no group differences at 6 months. However, at 14 months, the ASD group had significantly lower scores than the TD group but was not different from the LD group. At 24 months, the ASD group was significantly delayed compared to both of the other groups. It is important to note that standard scores were within the average range for all groups at 14 months. By 24 months, however, the ASD group scored 1.5 standard deviations below average, while the other two groups continued to perform in the average range.

In addition to decreased performance on standardized measures, researchers have documented delayed posture development among HR infants in more naturalistic contexts. Iverson and Wozniak (2007) observed a group of HR and LR infants in their homes while engaging in everyday activities at monthly intervals from 5 to 14 months with follow up at 18 months. In order to measure postural stability, the authors examined how long infants spent in each posture. They found that HR infants' posture bouts were significantly shorter than those of LR infants, which suggests that HR infants may have had more difficulty sustaining postures for an extended period of time due to instability. In addition, as compared to the LR group, the HR group was delayed in achieving the unsupported sitting milestone. Because this study ended at 18 months, it was not possible to conduct ASD diagnostic assessments with the HR infants. Thus, it is unclear as to whether the differences observed between LR and HR infants can be accounted for by a subset of HR infants who may have gone on to receive an ASD diagnosis.

More recently, Nickel et al. (2013) gathered in-home, prospective, longitudinal behavioral data from HR infants and a comparison group of LR infants at 6, 9, 12, and 14 months. Infants were followed to the age of 36 months in order to conduct outcome assessments. This permitted the authors to examine differences between LR infants and HR infants without ASD and to look more specifically at the small subset of infants who were ultimately diagnosed with ASD. Consistent with the prior findings, differences were observed between the LR and HR groups in sitting. Specifically, relative to LR infants, HR infants spent significantly more time in supported sitting and significantly less time in unsupported sitting at 6 months. Because time spent executing an emergent behavior can be utilized as a proxy for proficiency in performing the behavior (e.g., Iverson & Thelen, 1999), this finding suggests that HR infants may have more difficulty than LR infants at maintaining an unsupported sitting posture at 6 months. Another difference between HR and LR infants was observed at 14 months. Although almost all of the HR infants could stand independently by 14 months, they were more likely than LR infants to transition back to an all-four posture, which is biomechanically less advanced than standing. The four infants who eventually received an ASD diagnosis exhibited delays in unsupported sitting, all-fours, and standing postures compared to infants without an ASD diagnosis (combined LR and HR infants).

While the studies cited above suggest that HR infants who do not go on to receive an ASD diagnosis may have postural control difficulties (e.g., decreased stability in sitting and standing postures) in the first two years, small sample sizes preclude any type of subgroup analyses that could potentially tease apart the expanded variability in the HR group. It may be particularly important to distinguish HR infants with language delay but no ASD from those with no diagnosis in light of finding that children with language impairments are often significantly delayed in early posture milestones (Trauner, Wulfeck, Tallal, & Hesselink, 2000; Viholainen, Ahonen, Cantell, Lyytinen, & Lyytinen, 2002). Thus, there is a need for research with larger samples that can investigate individual patterns of postural development and delays in HR infants who do not go on to receive an ASD diagnosis.

1.2 VOCALIZATION DEVELOPMENT

1.2.1 Typical Development

Long before infants speak, they produce an array of pre-speech vocalizations that develop systematically, reflecting a maturing speech production capacity (Oller, 1995). In the first months of life, infants produce largely vowel sounds (e.g., [eeee]. However, with increasing control of the vocal tract, tongue, and lips they begin making syllabic vocalizations (i.e., vocalizations that contain consonant-vowel (CV) syllables). While most TD infants reach the syllabic vocalization milestone between 4 and 6 months, syllabic vocalizations become increasingly more speech like over time (Oller, 2000). Whereas early syllabic vocalizations are characterized by a slow transition from consonant to vowel (e.g. [baaaaaa]), by 8-10 months syllabic vocalizations often consist of a rapid transition between the consonant and vowel (e.g., [ba]; [da]; Oller, 1980, 2000; Stark, 1980). These later emerging syllabic vocalizations are referred to as canonical syllables and possess acoustic patterns very similar to adult speech (Oller, 2000).

The production of syllabic vocalizations is perhaps the most important achievement in pre-speech vocal development because of the robustness of this milestone across infants and its close connection to the emergence of language (Oller, 2000). There is a high degree of phonological similarity between syllabic vocalizations and first words (e.g., Oller, Wieman, Doyle, & Ross, 1976; Stoel-Gammon & Cooper, 1984). For example, individual infants tend to prefer the same syllable types in their early word production as they did in pre-speech syllabic vocalizations (Vihman, Macken, Miller, Simmons, & Miller, 1985). In addition, the timing of emergence of reduplicative babble (strings of CV units) is related to subsequent expressive vocabulary development. Specifically, late onset of reduplicative babble (i.e., after 10 months) is highly predictive of future expressive language problems (Oller, Eilers, Neal, & Schwartz, 1999; Stoel-Gammon, 1989), suggesting that delayed babbling is an early marker of difficulties with phonological capabilities that impact language production.

1.2.2 Autism Spectrum Disorder

Delays and/or deficits in language and communication are core features of ASD (American Psychiatric Association, 2013), and absence of first words and phrase speech appear consistently among the first concerns reported by caregivers of children with ASD (e.g., De Giacomo & Fombonne, 1998; Wetherby et al., 2004). While less empirical attention has been devoted to vocalizations, existing findings point to disruptions in young children with ASD, specifically with regard to volubility (i.e., rate of vocalizations, measured in terms of frequency of utterance productions) and syllabic vocalizations (e.g., Oller et al., 2010; Warren, Gilkerson, Richards, & Oller, 2010; Wetherby et al., 2007; Wetherby et al., 2004; Wetherby, Yonclas, & Bryan, 1989).

In a recent study that collected all-day vocalization recordings of children from 16 to 48 months of age, automated analyses indicated that children with ASD exhibit low volubility as compared to TD controls (Warren et al., 2010). With regard to syllabic vocalizations in children with ASD, Wetherby et al. (1989) found that at 3 years of age, the proportion of vocalizations containing a consonant produced was significantly lower for children with ASD than a group of TD children matched on expressive language level. More recently, in two large-scale prospective longitudinal studies with general population samples screened to identify young children with developmental delays (DD) and ASD, Wetherby and her colleagues (Wetherby et al., 2007; Wetherby et al., 2004) reported that relative to TD children, children with ASD exhibited a lack of vocalizations containing a consonant and produced fewer different consonant types, suggesting that they may have difficulty with the production syllabic vocalizations. However, consistent with prior research (Plumb & Wetherby, 2013; Sheinkopf et al., 2000), no differences were observed between children with ASD and their DD peers. Thus, decreased consonant production in young children with ASD may not be specific to ASD, but rather a more global marker of cognitive and language deficits.

Based on findings from the studies of young children with ASD cited above, Patten et al. (2014) hypothesized that decreased volubility and delays in syllabic vocalizations may be among the earliest behavioral markers of risk for a later ASD diagnosis. To test this prediction, they conducted a retrospective video study examining vocalizations at 9-12 and 15-18 months in a sample of infants who were later diagnosed with ASD and a sample of TD infants. Results indicated that infants later diagnosed with ASD displayed significantly lower volubility and rates of syllabic vocalizations than TD infants at both ages.

1.2.3 Infants at Heightened Risk for ASD

While there has been a major focus on studying language and communication in HR infants, there is a comparatively little research investigating early pre-speech vocalization development (Jones et al., 2013). This is surprising given the fact that pre-speech vocalizations, especially syllabic vocalizations, are a precursor to language and thus delays can be detected long before delayed or atypical language development can be observed. In addition to increased risk for ASD, even those HR infants without ASD are more likely than their LR peers to have a language impairment by 36 months (Yirmiya et al., 2006). By comparing HR infants who are eventually diagnosed with ASD to HR infants with language delays but no ASD, it is possible to examine whether delayed pre-speech vocalization development is specific to ASD or is instead a more general marker for future language delay regardless of ASD diagnosis.

The two studies that have focused on pre-speech vocalizations in HR infants suggest that a pattern of delay can be identified in the second half of the first year (Iverson & Wozniak, 2007; Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011). In a longitudinal study, Iverson and Wozniak (2007) observed the age of onset of reduplicative babbling in HR and LR infants. The HR group contained a significantly higher proportion of infants who were delayed relative to the LR group (HR=29%, LR=0%). However, because this study ended at 18 months, ASD evaluations were not completed and thus comparisons were made based on risk group status rather than diagnostic outcome.

In a cross-sectional study of HR infants, Paul et al. (2011) examined production of pre-speech vocalizations at 6, 9, and 12 months during a 5-minute parent-child interaction in the laboratory. Relative to LR infants, HR infants on average had decreased volubility across the three age points. HR infants as a group also produced lower proportions of vocal utterances that consisted of CV syllables at 9 months, but there was not a significant difference between groups at 6 or 12 months. Because of the cross-sectional design of this study, it is difficult to determine whether the absence of group differences at 12 months signifies that the HR infants had caught up to their LR peers by this age. In addition, it is important to note that 5 minutes is an extremely brief window of time in which to observe spontaneous production of vocalizations, especially at 6 months.

One limitation of both of these studies is the lack of diagnostic outcome data for HR infants. There is a need for research on vocalization development in HR infants that includes diagnostic outcome information. Because HR infants who do not develop ASD are also at increased risk for language and communication delays, prospective studies of HR infants have the potential to identify developmental trajectories of pre-speech vocalizations in infants who later exhibit language impairments not associated with ASD. This will permit examination of whether delayed and/or atypical patterns of pre-speech vocalization development are specific to ASD.

1.3 RELATIONS BETWEEN UNSUPPORTED SITTING AND SYLLABIC VOCALIZATION DEVELOPMENT

The emergence of unsupported sitting is a major event in infant development that is related to advances in a variety of other skills, including manual object exploration (Rochat & Goubet, 1995; Soska, Adolph, & Johnson, 2010; Spencer, Vereijken, Diedrich, & Thelen, 2000), visuomotor coordination (Bertenthal, Rose, & Bai, 1997), and upright face processing (Cashon, Ha, Allen, & Barna, 2013). In addition, the unsupported sitting milestone is associated with fundamental changes in caregiver-infant social and communicative interactions (Fogel, 1997). Taken together, these findings highlight the importance of studying the role that sitting plays in development not only within the motor domain (e.g., in motor planning), but also across domains (e.g., in communication and language).

One area of development that may also be influenced by learning to sit is vocalization development. The achievement of unsupported sitting results in substantial changes in respiration and in the position of the speech articulators (e.g., tongue and jaw). In the sitting position, infants' rib cages are freed, allowing them to breathe more deeply and maintain subglottal pressure more consistently than when in a supine posture. This may facilitate production of longer strings of utterances in a single breath that are better controlled. In addition, with the new upright head position, the jaw opens and closes more easily and the tongue falls to a more forward position in the oral cavity. Ultimately these changes may enhance the production of syllabic vocalizations (e.g., MacNeilage & Davis, 2000).

In an unpublished dissertation, Yingling (1981) explored this possibility by following a group of infants bi-weekly starting at 5.5 months and continuing until one month following the onset of unsupported sitting. In order to meet criteria for unsupported sitting, infants were required to independently maintain an upright seated position for at least 5 minutes (*M* = 7 months; *SD* = .38). At each session, infants were recorded while playing on their own and vocalizing for approximately 15 minutes. Prior to the onset of unsupported sitting, infants were placed in supine or prone postures during the recording period. Recordings from four sessions (two before and two after the unsupported sitting milestone was reached) were examined using spectrographic analyses. Findings revealed that as infants became more skilled at maintaining an unsupported sitting posture, syllabic vocalizations became more frequent.

Long before infants can support themselves in a sitting posture, they are held upright by caregivers and furniture. Although one might expect these earlier forms of supported sitting to confer the same benefits for vocal skills as infant sustained supported sitting or unsupported sitting, there is evidence suggesting that this is not the case. In a study of 12 month-old infants with

Cerebral Palsy, Levine (1999) found that poorly developed head and trunk control was related to lower quality vocalization production (i.e., more vowel-like sounds and fewer well-formed syllabic vocalizations) while in the sitting posture. This relationship is likely due to the fact that difficulty with head and neck control interferes with controlled respiration, which is a critical element for the production of syllabic vocalizations. And while very well developed control of the head and neck is a prerequisite for unsupported sitting, proficiency in sitting when sustained by an adult requires only minimal stability of the head and trunk.

One implication of the Yingling (1981) study is that delays in unsupported sitting may have cascading effects that impact the development of syllabic vocalizations. HR infants represent an ideal population for examining this question because, as a group, even those infants who do not receive a later ASD diagnosis exhibit large variability in development across multiple domains, with a relatively high percentage demonstrating delayed developmental trajectories (Rogers, 2009). Longitudinal research with HR infants focusing on vocalization development in relation to sitting development provides a test for the hypothesis that even a small disruption in a very basic and early emerging motor skill – unsupported sitting – can lead to disturbances beyond the motor domain (Iverson, 2010; Thelen, 2004).

1.4 THE PRESENT STUDY

Although it is well established that young children with ASD demonstrate difficulties with postural control and syllabic vocalization production (e.g., Fournier, Hass, et al., 2010; Oller et al., 2010), relatively little is known about the emergence and course of development of these behaviors in infants eventually diagnosed with ASD. The initial prospective studies examining posture and vocalizations in HR infants suggest that a pattern of delay in both of these areas in the first year may precede any observable social and communicative impairments in infants later diagnosed with ASD (e.g., Leonard et al., 2013; Nickel et al., 2013; Paul et al., 2011). However, because these studies have often been cross-sectional and have lacked information about diagnostic outcome, there is a need for studies that follow infants to 36 months to allow examination of developmental trajectories in relation to diagnostic outcome. Therefore, the first aim of the proposed project is to describe trajectories of posture and vocalization development from 6 to 14 months in HR and LR infants and to evaluate the extent to which delays or impairments predict a later ASD diagnosis at 36 months of age. Based on the literature reviewed above, the following predictions were made.

A. Posture – Compared to LR infants, HR infants as a group, and particularly those later diagnosed with ASD will:

1. Have smaller posture repertoires (i.e., the number of *different* postures in which infants are observed in the course of the observation period) at all ages;
2. Continue to be observed in the lying posture at older ages (i.e., 10-14 months)
3. Spend more time in supported sitting and less time in the biomechanically more challenging unsupported sitting posture, especially when unsupported sitting is first developing (i.e. 6 months);
4. Display an initial delay in the emergence of the All-4 posture between 8 to 10 months;
5. Exhibit slower growth in supported standing across the 6 to 14-month period;
6. Show delays in the emergence of unsupported standing from 12 to 14 months;
7. Be less likely to sustain themselves and more likely to rely on caregiver support while in the sitting and standing postures.

B. Vocalization – Compared to LR infants, HR infants as a group, and particularly those later diagnosed with ASD or language delay (LD) will:

1. Show decreased volubility (i.e., total vocalization production) from 6 to 14 months;
2. Display slower growth in syllabic vocalization production from 6 to 14 months.

Yingling (1981) points to a possible mechanism for vocalization development, namely that the attainment of unsupported sitting alters infants' experiences with their own bodies, leading to exploration of the newly reconfigured vocal tract, expanded lung capacity, and greater control over speech timing, all of which are relevant for the production of syllabic vocalizations. While Yingling's (1981) study focused on TD infants who were not delayed in the development of sitting, an implication of this research is that delays in unsupported sitting may be related to subsequent delays in syllabic vocalization development. The HR infants to be included in the current research represent an ideal way to obtain the wide variability in developmental trajectories needed to evaluate this possibility. Thus, a second aim of this study is to examine the relationship between sitting development and advances in vocalization development.

As mentioned previously, infant sustained sitting typically emerges at 5 months and unsupported sitting by 6 months, with 90% of all TD infants sitting without support by 8 months (Piper & Darrah, 1994). In addition, it is between 5 and 10 months when syllabic vocalizations are emerging and becoming progressively more frequent (Koopmans-van Beinum & van der Stelt, 1986; Oller, 1980; Stark, 1980). Therefore, this aim will focus on data from the 6- and 8-month observation sessions. Based on the literature reviewed above, the following hypotheses were made:

1. At 6 and 8 months, infants in both the HR and LR groups who have achieved the unsupported sitting milestone will produce significantly more syllabic vocalizations relative to infants who are not yet able to sit without support.

2. At 6 and 8 months, infants in both the HR and LR groups will produce significantly more syllabic vocalizations while sitting than while lying.

2.0 METHOD

2.1 PARTICIPANTS

Demographic information for participants in the current study is presented in Table 1. Participants consisted of 59 (29 males) infants at heightened biological risk for an ASD diagnosis due to having an older sibling diagnosed with Autistic Disorder (HR infants; e.g., Ozonoff et al., 2011). Eligible infants were full-term, from uncomplicated pregnancies and deliveries, had 5-minute neonatal Apgar scores within the normal range (9 or better; Apgar, 1953), and were from English-speaking homes. The full HR sample was predominately Caucasian and non-Hispanic (88%). In addition, one Asian-American, one African-American, and five Hispanic infants took part in the study.

All HR families were recruited through the University of Pittsburgh Autism Research Program as well as support organizations, local agencies, and schools serving children with ASD. Prior to each HR infant's enrollment, the Autism Diagnostic Observation Schedule (ADOS-G; Lord et al., 2000) was administered to the older sibling by a trained clinician to confirm the ASD diagnosis. For an infant to participate, the older sibling must have met DSM-IV TR criteria for Autistic Disorder *and* scored above the threshold for Autism on the ADOS-G. Informed consent was obtained prior to the first visit.

An additional 25 infants (10 males) with no family history of ASD (i.e., no first- or second-degree relatives diagnosed with ASD) served as a low risk (LR) comparison group. LR infants were followed longitudinally as part of a separate completed study of vocal-motor coordination in TD infants (Iverson, Hall, Nickel, & Wozniak, 2007). Nine of these infants were first born and 16 had at least one older TD sibling. All of these infants were also full-term, from uncomplicated pregnancies and deliveries, had 5-minute neonatal Apgar scores within the normal range (9 or better; Apgar, 1953), and were from English-speaking homes. Similar to the HR sample, LR infants were predominately Caucasian and non-Hispanic (96%). The remaining infant was Asian-American. Families were recruited through published birth announcements and word of mouth. No developmental concerns were ever reported for any of the LR infants during the course of their involvement in the study. In addition, we have remained in contact with these families, and no children have subsequently received a diagnosis of a developmental disorder of any sort (e.g., ASD, language impairment).

The average maternal age at infant enrollment did not differ significantly by group for mothers (M_{HR} = 34.15, SD = 4.38; M_{LR} = 31.77, SD = 4.58). However, fathers of HR infants were significantly older than fathers of LR infants (M_{HR} =35.90, SD = 4.15; M_{LR} = 32.83, SD = 4.21). Over 90% of mothers and fathers in both HR and LR groups had some college or graduate school experience and there were no significant differences between groups in education levels. Parental occupations were identified for the purpose of providing a general index of socioeconomic status. Because 46% of HR mothers and 33% of LR mothers were home raising their children, Nakao-Treas occupational prestige scores (Nakao & Treas, 1994) were calculated for fathers' occupations. For 5 cases (HR = 3; LR = 2), it was impossible to identify the fathers' occupation with enough precision to assign a prestige score. Results from the remaining families indicated that although the mean prestige score was slightly higher for the HR group (M = 57.50, SD = 16.20) than the LR group (*M* = 55.21, *SD* = 14.41), both groups generally fell within the managerial/professional range and the difference was not statistically significant.

2.2 PROCEDURE

Infants in both groups were observed at home with a primary caregiver for approximately 30-45 minutes at regular intervals. LR infants were followed biweekly from 2 to 19 months of age. HR infants were followed monthly from 5 to 14 months, with 18, 24, and 36 months follow-up visits. Observations occurred within three days of the monthly anniversary of the infant's birth and at times when the caregivers thought the infants would be most alert and playful. All home visits were video- and audio-recorded. To enhance the quality of audio recording, infants wore a small wireless microphone clipped to a cloth vest worn over their clothing during the session. The present study focused on data obtained during the 25-minute naturalistic and semi-structured play segments from the monthly home observation sessions at 6, 8, 10, 12, and 14 months and from standardized assessments at the HR infants' 18, 24, and 36 month follow-up visits. Typically, the naturalistic segment occurred at the beginning of the visit and was followed by the play segment.

Naturalistic and play segments. At all five ages, dyads were observed in two major contexts at home for at least 25 minutes. The first 15-minute segment consisted of unstructured, naturalistic observation. Parents were asked to continue their normal activities during this time; no attempt was made to structure this portion of the session in any way (with the exception that parents were asked to keep the television off). Typically, the infants played on the floor with available toys during this time. Following the naturalistic segment, infants and parents participated in a 10-minute semi-structured free play and social interaction with favorite toys in which parents were instructed to play with their infant as they normally would.

Diagnostic Assessment and Classification. The Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al., 2000) was administered to all HR infants at 36 months of age by a research reliable evaluator who was blind to all previous study data. The ADOS is a structured play-based interaction designed to assess symptoms of ASD across the social interaction, communication, and play domains. The presence of repetitive behaviors and interests is also noted. The individual items on the ADOS are scored from 0 to 3, with higher scores indicating more profound impairment. These items are then transferred to a scoring algorithm that permits diagnostic classification of ASD or Autism when domain scores meet instrument thresholds. The ADOS has been shown to distinguish individuals with ASD reliably from both TD children and children with other developmental disorders (Lord et al., 2000).

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) was administered at the 18, 24, and 36 month follow up visits for all HR infants. The MSEL is a standardized developmental assessment that provides a comprehensive measure of general cognitive functioning from birth to 68 months of age (Mullen, 1995). The MSEL includes Fine Motor, Visual Reception, Expressive Language, and Receptive Language subscales through 68 months. A Gross Motor subscale can also be administered prior to 33 months. Internal consistency ranges from .83 to .95.

The MacArthur-Bates Communicative Developmental Inventory (CDI; Fenson et al., 2002) was completed by parents of HR infants at each of the follow up visits. The CDI is a reliable and valid parent report measure of language and communication development and has been used with infants and children with typical development, specific language impairment, Down syndrome and ASD (e.g., Charman, Drew, Baird, & Baird, 2003; Dale, Bates, Reznick, &

Morisset, 1989; Fenson et al., 1994; Luyster, Qiu, Lopez, & Lord, 2007; Miller, Sedey, & Miolo, 1995; Mitchell et al., 2006; Thal, O'Hanlon, Clemmons, & Fralin, 1999). At 18 months, parents completed either the Words and Gestures form of the CDI (CDI-WG) or the Words and Sentences form (CDI-WS) depending on their child's general language level. The CDI-WG consists of two parts. Part I is a 396 item vocabulary checklist in which parents are asked to check: a) items that their child only understands (receptive); and b) those that the child both says and understands (receptive and expressive). Part II focuses on the production of early gestures and play actions. The CDI-WS also consists of two parts: a 680- expressive vocabulary checklist and a section on children's use of morphology and syntax. Thus, if a child was producing relatively few words (as indicated by the parent and observed by the experimenter) and had no two-word combinations at 18 months, the CDI-WG was administered. If a child had an extensive productive vocabulary and some word combinations, the CDI-WS was administered. At 24 months, all parents completed the CDI-WS version. At the final 36-month observation, parents completed the CDI-III, which is designed for children ages 30-37 months and consists of a 100-item expressive vocabulary checklist, 12 sentence pairs assessing grammatical complexity, 12 questions concerning semantics and pragmatics.

Using the standardized measures described above, HR infants were classified into one of three outcome groups following the 36 month home visit and outcome assessment: a) ASD; b) Language Delay without ASD (LD); and c) No Diagnosis (ND). Table 2 presents scores from the MSEL and the ADOS for each of the three HR outcome groups at the 36 month visit. While LR infants did not undergo a formal evaluation process to confirm typical development, there were never any developmental concerns noted by caregivers or research staff. Further, no LR infant received early intervention services.

a) ***ASD***. Fourteen HR infants were classified as ASD (10 male). In order to receive a diagnosis of ASD, infants had to have a score on the ADOS that met or exceeded algorithm cutoffs for ASD or AD and a trained clinician needed to confirm the diagnosis using the DSM-IV-TR criteria.

b) ***Language Delay without ASD.*** Seventeen HR infants were classified as LD without ASD (9 male). To be categorized as LD, infants had to meet one of the following criteria and **not** receive a diagnosis of ASD:

   - Standardized scores on the CDI at or below the 10th percentile at more than one time point between 18 and 36 months (e.g., Gershkoff-Stowe, Thal, Smith, & Namy, 1997; Heilmann, Weismer, Evans, & Hollar, 2005; Robertson & Weismer, 1999; Weismer & Evans, 2002).
   - Standardized scores on the CDI-III at or below the 10th percentile and standardized scores on the Receptive and/or Expressive subscales of the MSEL equal to or greater than 1.5 standard deviation below the mean (e.g., Landa & Garrett-Mayer, 2006; Ozonoff et al., 2010).

c) ***No Diagnosis (ND).*** The remaining 28 HR infants (10 male) were classified as ND because they did not meet any of the above criteria for ASD or LD.

A clinical referral for further evaluation was made at the 36-month evaluation if the child received a diagnosis of ASD or Language Delay (LD). In addition, HR infants were given a clinical referral at any time during the course of the study if parents indicated concern about their infant's development and asked for a referral. Infants referred for evaluation and possible intervention were retained in the sample, and types and frequency of services received were documented. Appendix

A provides a detailed summary and description of the referrals, evaluations, and early intervention services for all HR infants by outcome group.

2.3 CODING

Coding of infant posture and vocalizations during the 25-minute observation was carried out by a team of coders blind to infants' group membership and outcome classification using The Observer (The Observer Video-Pro version XT, Noldus Information Technology, 2000) a video-linked computer program.

Posture. Infant posture was coded continuously using procedures adapted from Nickel et al. (2013). Onset and offset times for each posture were identified, and only postures sustained for at least 1s were coded. Postures were further classified according to posture type (e.g., Lying, Supported Sitting, Unsupported Standing). A brief definition of each posture is presented in Table 3 (for further details, see Appendix B).

Supported Sitting and Supported Standing postures were further categorized on the basis of the source of support. *Infant Sustainment* involved the infant using his or her own body or hands for support with no contact from the caregiver (e.g., sitting in a tripod position with hands on the floor; leaning against a couch while standing). *Caregiver Sustainment* involved active and firm support from the caregiver. Although this not a frequent occurrence, all instances in which the infant was contained in an infant seat or high chair were excluded from analyses.

Vocalization. To assess overall *Volubility* (total frequency of vocalizations), all vocalizations including non-word vocalizations and words were coded. Non-word vocalizations were defined as uninterpretable speech sound productions, excluding vegetative sounds (e.g., sneezing, coughing, and breathing) and affective vocalizations (e.g., crying and laughing), as these sounds are not considered to be precursors to speech (Oller, 2000; Stoel-Gammon, 1989). Words were coded if they were either actual English words (e.g., "tree," "ball," "red") or speech sounds that the child consistently used to refer to a specific object or event (e.g., using "baba" to refer to a bottle in a variety of (e.g., Iverson, Capirci, & Caselli, 1994; Iverson & Goldin-Meadow, 2005; Sauer, Levine, & Goldin-Meadow, 2010). As a measure of vocal quality, vocalizations were further classified as *Syllabic Vocalizations* if they contained at least **one** consonant-vowel unit (e.g., [ba] [bbbbaaaa] [babababa] [badila]; Oller, 1980; Oller, 2000; Stark, 1980). For further details on vocalization coding, see Appendix C.

Unsupported Sitting Milestone. As part of the larger longitudinal studies, all primary caregivers were given a baby journal and a list of early developmental milestones with clear definitions. Upon enrollment, caregivers were asked to use the baby journal to record the date that they first observed their infant successfully exhibit the milestone behaviors. This study focused on the Unsupported Sitting milestone which was defined as, "Sits upright without support and without toppling over for at least 30 seconds." At each of the visits, the researcher reviewed the milestone criteria and specifically asked if the infant had reached any of the milestones on the list. The achievement of Unsupported Sitting was credited when the caregiver reported the onset of the behavior *and* the behavior was verified by the researcher during the given session.

2.4 RELIABILITY

Prior to initiation of coding, coders were trained to a minimum criterion of 80% agreement on three consecutive videos for all variable. There were regular reliability meetings with both the posture and vocalization coding teams in order to prevent coder drift and allow for estimations of reliabilities. Disagreements were resolved by joint viewing and discussion.

Interrater reliability was assessed via independent coding of 22% (n = 84) of the video clips for posture variables and 20% (n = 78) of the video clips for vocalization variables. Reliability videos were chosen so as to include participants from both groups and at all 5 age points. For posture identification, mean percent agreement averaged across the 84 videos was 86.8% (range: 77.5-97.8%). Mean Cohen's Kappa statistic for classification of sustainment type (infant vs. caregiver) was 0.89 (range: 0.80-0.96). For vocalization variables, inter class correlation coefficients (ICCs) between the raw total counts of the independent raters were calculated. The ICCs were .92 for Total Vocalizations and .81 for Syllabic Vocalizations.

2.5 ANALYTIC APPROACH

The first aim of this study was to explore developmental trajectories of posture and vocalization development from 6 to 14 months in HR and LR infants. As noted above, the study protocol consisted of 15 minutes of naturalistic observation and 10 minutes of interactive play per session, which resulted in a total of 25 minutes of observation coded for each participant. Average session lengths were highly similar across outcome groups (LR: *M* = 24.70, *SD* = 1.64; HR-ND: *M* = 24.35, *SD* = 2.43; HR-LD: *M* = 24.46, *SD* = 2.43; HR-ASD: *M* = 25.00, *SD* = 0.57). However, because session length sometimes varied slightly, posture variables were converted to percentages by dividing the total amount of time spent in a specific posture by the length of the observation[1].

[1] Before conducting analyses all percentage data were arcsin transformed (2*arcsin[sqrt(x)]) to correct for nonnormality that typically results from percentage data (Cohen et al., 2013). Models were run with both the arcsin

Vocalizations were coded as frequencies, so these variables were converted to rates per 10 minutes by dividing the total frequency by length of observation in minutes, then multiplying by 10. As can be seen in Table 4, data were not available for all of the infants at each age point because of missing visits (e.g., infant not yet enrolled in study; visit missed due to illness or other unanticipated family events) and/or unusable video (e.g., malfunction of video, lighting issues, and sound equipment failure)[2].

Hierarchical Linear Modeling (HLM; Raudenbush & Bryk, 2002) was utilized to describe differences in growth trajectories of early posture and vocalization development based on infant risk status and outcome classification (LR, HR-ND, HR-LD, and HR-ASD). HLM is an appropriate analytical tool for data consisting of multiple time points nested within individuals and can assess data at two levels. First, HLM assess variation *within individuals* over time (i.e., growth trajectories; Level 1), and second, it assesses variation *between individuals* in growth trajectories (Level 2). HLM can accommodate unequally spaced data collection occasions, different data collection schedules, and missing data (Huttenlocher, Haight, Bryk, Seltzer, & Lyson, 1991; Singer, 1998; Willett, Singer, & Martin, 1998). Thus, multilevel models both accommodated nested, hierarchical data and take appropriate advantage of all observations, resulting in greater power for the detection of effects (Raudenbush & Bryk, 2002; Singer & Willett 2003).

All models were estimated in HLM 6.08 using Full Information Maximum Likelihood estimation (FIML; Raudenbush, Bryk, & Congdon et al., 2010). Although details of the modeling

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transformed and non-transformed data. In all cases, normality improved with the arcsin transformation but results remained unchanged (although significance values may have attenuated or strengthened). Thus, for ease of interpretation, descriptive data (e.g., mean percentages) as well as the coefficients and standard errors for the HLM models reported below are those for the *untransformed* percentages.

[2] Although posture and vocalization coding was completed with the same infants, there were 3 instances in which lighting was too poor to code posture and 2 instances in which sound quality was too poor to code vocalizations.

process differed slightly for each dependent variable (e.g., fixing the random Level 2 variation in intercept when no between-infant differences were detected in the unconditional model), the same general procedure was used in all cases. For each variable, the process began with running a fully unconditional linear growth model with TIME (in months) as a predictor at Level-1 and with no predictors at Level-2. In order to determine the most appropriate model of individual change, a quadratic model was run next by including $TIME^2$, and finally a cubic model was run by including $TIME^3$. Separate chi-square tests were used to test the change in deviance from the linear to the quadratic model and from the quadratic to the cubic model. Test significance represents a significant reduction in deviance from one model to the next, which generally indicates that the model with more parameters is a better fit for the data. Visual examination of individual infant posture and vocalization growth trajectories was also useful in determining the most appropriate model of individual change (i.e., linear, quadratic, cubic; Raudenbush & Bryk, 2002) for each dependent variable. Of the 11 dependent variables, a linear growth model was the best fit in two cases and a quadratic growth model was the best fit in nine cases.

At Level 1 (within-person) of our final conditional models, HLM estimated individual growth trajectories in posture and vocalization variables from 6 to 14 months as a function of time. TIME was measured in months and was always centered at the initial data collection point (i.e., 6 months). The quadratic ($TIME^2$) age variable was calculated by squaring the centered linear age variable. The Level 1 model for a quadratic growth model is shown in equation 1.

$$(1)\ Y_{it} = \pi_{0i} + \pi_{1i}(TIME_{it}) + \pi_{2i}({TIME_{it}}^2) + e_{it}$$

Here, π_{0i} represents the intercept for infant i at the centered time point, π_{1i} represents the instantaneous linear growth rate at the centered time point, and π_{2i} represents the quadratic growth rate or acceleration parameter.

At Level 2 (between individuals), outcome group (HR-ND, HR-LD, HR-ASD) and gender (SEX) were included. These variables are considered time invariant predictors because they remained constant across observations for a given infant. The LR group was used as the comparison group, thus analyses at Level 2 examined differences in growth trajectories between LR infants and the three outcome groups of HR infants controlling for gender. The Level 2 models for a quadratic growth model are shown in Equations 2-4:

(2) $\pi_{0i} = \beta_{0LR} + \beta_{01}(SEX_i) + \beta_{0HRND}(HRND_i) + \beta_{0LD}(LD_i) + \beta_{0ASD}(ASD_i) + r_{0i}$

(3) $\pi_{1i} = \beta_{1LR} + \beta_{11}(SEX_i) + \beta_{1HRND}(HRND_i) + \beta_{1LD}(LD_i) + \beta_{1ASD}(ASD_i) + r_{1i}$

(4) $\pi_{2i} = \beta_{2LR} + \beta_{21}(SEX_i) + \beta_{2HRND}(HRND_i) + \beta_{2LD}(LD_i) + \beta_{2ASD}(ASD_i) + r_{2i}$

Here, variation in the intercept (π_{0i}), instantaneous linear growth (π_{1i}), and quadratic growth (π_{2i}) are modeled as a function of four time-invariant infant characteristics. Thus, the coefficients (β) represent deviations from the LR group on each of these terms. For example, β_{1ASD} represents the deviation of the HR-ASD from the LR group in instantaneous linear growth.

For several of the variables, targeted post hoc analyses were performed by re-centering the TIME variable so that the trajectories' anchor, or intercept, systematically varied. This improved the interpretability of the growth trajectories by allowing us to determine the point at which developmental trajectories of different outcome groups either diverged or converged. Further exploratory analyses addressed specificity by examining potential differences between the HR-ASD and the other HR groups (HR-ND and HR-LD) by rotating the reference group.

Assumptions underlying statistical models were checked by assessing normality and homoscedasticity. In the few cases where outliers were identified, these values were removed and models were fitted again. While normality tended to improve with outlier removal, results remained unchanged. Therefore, the final models included all participants in the study with available data. Because the data tended to violate the assumption of homoscedasticity, robust standard errors are reported.

3.0 RESULTS

The first overarching goal of this research was to examine differences in trajectories of early posture and vocalization development between a group of LR infants and three groups of HR infants (HR-ND, HR-LD, and HR-ASD) in order to better understand the very early development of HR infants with and without an eventual diagnosis of ASD. Data analyses focused on two main questions: a) Do infants with and without risk for ASD demonstrate differences in posture and vocalization development between 6 and 14 months of age?; and b) To what extent does developmental delay or impairment in posture and vocalization development predict a later ASD or LD diagnosis in HR infants? Data on posture development are presented first, followed by those for development of vocalizations.

Prior to conducting the main analyses, preliminary analyses were performed to ensure that any observed differences in posture and vocalization development between outcome groups were not due to the greater number of first-born infants in the LR group. Mann-Whitney *U* tests revealed no effects of birth order (first- versus later-born) on any of the posture or vocalization variables.

3.1 POSTURE DEVELOPMENT

3.1.1 Posture Repertoire

Because the 6 to 14 month developmental time frame is marked by the emergence of new postural skills, the first set of posture analyses focused on estimating growth over time in the diversity of infants' Posture Repertoires (i.e., the number of different postures in which infants were observed in the course of the observation). For this analysis, each posture was only counted once. Thus, if an infant was observed Lying, then moved to All-4, and then moved back to Lying, s/he would be credited with two postures. Infants could be credited with a maximum of eight postures: Lying, Infant Sustained Supported Sitting, Unsupported Sitting, Kneeling, All-4, Infant Sustained Supported Standing, Unsupported Standing, and Squatting. Descriptive data on Posture Repertoire are presented in Table 5 and the final model summary is presented in Table 6.

For the LR group, it was estimated that the posture repertoire increased from approximately 3 different postures at 6 months to 7 postures by 14 months. In terms of overall growth trajectory, the LR group demonstrated a slight deceleration (β_{2LR} = -.038, SE = .019, t = -1.976, p = .052), in which posture repertoire increased relatively quickly early on and rate of growth slowed over time. As is apparent in Figure 1, the HR-ND group displayed an extremely similar growth trajectory and did not differ from the LR infants on 6 month intercept or growth rates.

Although the HR-LD and HR-ASD groups did not differ from the LR group on linear growth rate or rate of deceleration, their posture repertoires were significantly smaller than the posture repertoire of the LR group at the 6-month intercept ($\beta_{0HR\text{-}LD}$ = -1.069, SE = 0.394, t = -2.714, p = .008; $\beta_{0HR\text{-}ASD}$ = -1.140, SE = 0.403, t = -2.827, p = .006). While the HR-LD group caught up to the LR group by 8 months, the HR-ASD group continued to exhibit a significantly smaller posture repertoire than the LR group at this age point ($p = .034$). From 10 to 14 months, posture repertoire size was comparable for the 4 outcome groups.

Additional post hoc analyses examining differences between HR-ASD infants and the other HR outcome groups indicated that the HR-ASD group also exhibited a smaller posture repertoire than the HR-ND group at the 6 month intercept ($p = .037$). There were no significant differences between the HR-LD and HR-ASD groups.

3.1.2 Posture Duration

The second set of posture analyses examined longitudinal change in the percent of time spent in each posture type. As noted above, session lengths varied slightly across individual infants. Thus, overall posture durations were converted to percentages by dividing the total amount of time spent in a specific posture (Lying, Supported Sitting, Unsupported Sitting, All-4, Supported Standing, and Unsupported Standing) by the length of the observation.

In order to assess change over time in the quality of Supported Sitting and Supported Standing, growth models were estimated for the percentages of time spent in Infant Sustained Supported Sitting and in Infant Sustained Supported Standing. These variables were created by dividing the time spent in Infant Sustained Supported Sitting (or Supported Standing) by the total time spent in Supported Sitting (or Supported Standing). Because infant sustainment and caregiver sustainment durations sum to equal 100% of Supported Sitting and 100% of Supported Standing time, it can be assumed that the reciprocal of infant sustainment is caregiver sustainment. Thus, growth trajectories were only estimated for infant sustainment for these postures.

It is important to note that in typical development the acquisition of more developmentally advanced posture types results in a decrease in the amount of time spent in earlier emerging posture types. For example, it is typical to see a decrease in time spent in the lying posture once infants are able to sit upright. Similarly, once infants can stand, they spend less time sitting or in all-4. Results are presented in the order of least developmentally advanced posture type (Lying) to the most developmentally advanced posture type (Standing). Descriptive data on posture durations are presented in Table 7 and the final model summaries are presented in Tables 8-11.

Lying. To examine overall developmental change in Lying, growth models were estimated for the percentage of time infants spent in the Lying posture (i.e., infant was Lying on stomach or back) from 6 to 14 months. The final conditional model indicated that LR infants spent approximately 36% of the observation in the Lying posture at 6 months. However, as can be seen in Figure 2, they declined rapidly in the percent of time spent in Lying, and by 10 months they were no longer observed in this posture, with the trajectory remaining flat and stable from 10 to 14 months. The HR infants without a later diagnosis of ASD (HR-ND and HR-LD) exhibited similar growth trajectories to the LR infants, and not surprisingly analyses indicated that there were no significant differences between the LR group and the HR-ND or HR-LD groups on any of the parameters.

Although the HR-ASD group did not differ significantly from the LR group in the growth parameters, post hoc analyses revealed that they spent a greater percentage of time in Lying at 10 and 12 months (p = .005, .007, respectively). The HR-ASD group also spent a greater percentage of time in Lying than the HR-ND group at both 10 and 12 months (p = .011, .045, respectively) and the HR-LD group at 10 months (p = .022).

Sitting. As noted above, Sitting was classified as either Supported Sitting (i.e., infant was supporting him/herself or being supported by a caregiver) or Unsupported Sitting (i.e., infant was seated without support from the hands, caregiver, or objects). In addition, to assess the quality of

Supported Sitting, all instances of Supported Sitting in which the infant was using his/her own hands or body for support and not receiving any support from a caregiver were classified as Infant Sustained Supported Sitting, and this variable was examined in a separate analysis.

Supported Sitting. Developmental change in the percent of time spent in Supported Sitting was analyzed first. At 6 months, LR infants spent approximately 24% of the time in Supported Sitting. Neither their instantaneous linear growth rate (β_{1LR} = -0.026, SE =0.018, t = -1.429, p = .157) nor their overall quadratic growth rate (β_{2LR} = 0.002 SE = 0.002, t = 1.004, p = .319) were significantly different from zero, resulting in a relatively flat growth trajectory (see Figure 3). The HR-ND group did not differ significantly from the LR group in intercept or growth rates, suggesting that the development of Supported Sitting is comparable for HR-ND and LR infants.

By contrast, the HR-LD and HR-ASD groups spent a greater percentage of time in Supported Sitting at 6 months than the LR group ($\beta_{0HR\text{-}LD}$ = 0.175, SE = 0.081, t = 2.151, p = .035; $\beta_{0HR\text{-}ASD}$ = 0.214, SE = 0.087, t = 2.455, p = .016). In addition, the HR-ASD group exhibited a significantly more negative instantaneous linear growth rate than the LR group ($\beta_{1HR\text{-}ASD}$ = -.065, SE = .029, t = -2.233, p = .028). As can be seen in Figure 3, the HR-LD and HR-ASD infants decreased relatively quickly in time spent in Supported Sitting from 6 to 10 months, and from 10 to 14 months they exhibited a low and stable trajectory similar to the LR and HR-ND groups.

The HR-ASD group was not significantly different from the HR-ND or HR-LD groups on any of the parameters.

Infant Sustained Supported Sitting. In order to assess change over time in the quality of Supported Sitting, growth models were estimated for the percentage of time spent in Infant Sustained Supported Sitting. For the LR group, the percentage of time in Infant Sustained Supported Sitting was estimated to be 44% at 6 months and increased by about 4% each month (see Figure 4). The HR-ND and HR-LD groups did not differ significantly from the LR group in intercept or growth rate, suggesting that the development of Infant Sustained Supported Sitting is comparable for HR infants without a later diagnosis of ASD and LR infants.

The HR-ASD group displayed a delayed developmental trajectory in Infant Sustained Supported Sitting. Specifically, the percentage of time in Infant Sustained Supported Sitting was significantly lower for the HR-ASD group than the LR group at 6 months ($\beta_{0HR\text{-}ASD}$ = -.294, SE = .089, t = -3.274, *p* = .002). However, the HR-ASD group increased twice as fast as the LR group ($\beta_{1HR\text{-}ASD}$ =.040, SE = .017, t = 2.346, *p* = .021). Post hoc analyses revealed that while differences between the HR-ASD and LR groups remained significant at 8- (*p* = .002) and 10-months (*p* = .017), the HR-ASD group caught up to the LR group by 12 months due to their relatively fast growth rate.

Additional post hoc analyses examining differences between HR-ASD infants and the other HR outcome groups indicated that the HR-ASD group displayed a lower percentage of time spent in Infant Sustained Supported Sitting at 6 and 8 months than the HR-ND (*p* = .008; .006) and HR-LD groups (*p* = .049; .032). At 10 months, the differences continued to be significant between the HR-ASD and HR-ND groups (*p* = .024).

Unsupported Sitting. Analyses of developmental change in the percent of time spent in Unsupported Sitting revealed that by 6 months, LR infants were already spending approximately 28% of the time in Unsupported Sitting. Furthermore, they exhibited a relatively flat growth trajectory with slight deceleration (see Figure 5).

As can be seen in Figure 5, the three HR groups (HR-ND, HR-LD, and HR-ASD) displayed a different pattern of development in Unsupported Sitting. Relative to the LR group, the percentage of time spent in Unsupported Sitting at 6 months was lower for the three HR groups, although the difference was only significant for the HR-ASD ($\beta_{0HR\text{-}ASD}$= -.225, SE = .071, t = -3.192, *p* =.002) and HR-LD groups ($\beta_{0HR\text{-}LD}$= -.154, SE = .080, t = -2.062, *p* =.042). In addition, as compared to the LR groups, all three HR groups displayed significantly faster instantaneous linear growth rates ($\beta_{1HR\text{-}ND}$ = .090, SE = .037, t = 2.403, *p* =.019; $\beta_{1HR\text{-}LD}$ = .106, SE = .036, t = 2.947, *p* = .004; $\beta_{1HR\text{-}ASD}$ = .120, SE = .035, t = 3.439, *p* < .001) and greater deceleration over time ($\beta_{2HR\text{-}ND}$ = -.009, SE = .004, t = -2.084, *p* =.040; $\beta_{2HR\text{-}LD}$ = -.010, SE = .004, t = -2.593, *p* = .011; $\beta_{2HR\text{-}ASD}$ = -.010, SE = .004, t = -2.442, *p* = .017). Post hoc analyses indicated that the HR-ND, HR-LD, and HR-ASD groups were all spending a greater percentage of time in Unsupported Sitting at 12 months than the LR group (*p* = .033, .011, .007, respectively).

The HR-ASD group was not significantly different from the HR-ND or HR-LD groups on any of the parameters.

All-4. Turning now to the development of the All-4 posture (i.e., infant was on hands and knees), growth models were estimated for the percentage of time infants spent in All-4 from 6 to 14 months. As can be seen in Figure 6, LR infants spent approximately 3% of the time in All-4 at 6 months, increased the amount of time they spent in this position from 6 to 10 month, and then displayed a decrease between 10 and 14 months. The development of All-4 for the HR infants without a later diagnosis of ASD (HR-ND and HR-LD) was comparable to that for LR infants, as indicated by no significant differences on any of the parameters.

The HR-ASD group had a significantly slower instantaneous linear growth rate than the LR group ($\beta_{1HR\text{-}ASD}$ = -.031, SE = .011, t = -2.690, *p* = .009) and the HR-LD group (*p* < .001), indicating that the rate of growth in All-4 in infants who go on to have ASD is initially slowed. In addition, the HR-ASD group did not demonstrate the decelerating pattern characteristic of the LR group ($\beta_{2HR\text{-}ASD}$ = .005, SE = .002, t = 3.614, $p < .001$) or the other two HR groups (HR-ND p = .036; HR-LD $p < .001$). Instead the HR-ASD group only demonstrated linear growth.

Post hoc analyses revealed that the percentage of time spent in All-4 was lower for the HR-ASD group than the LR, HR-ND, and HR-LD groups at 8 months (p = .002; .006; 025, respectively) and 10 months (p = .009; .038; 017, respectively). However, because of their linear pattern of growth, the HR-ASD group caught up to the other groups by 12 months, and at 14 months the percentage of time spent in All-4 by the HR-ASD group was significantly higher than that for the LR, HR-ND, and HR-LD groups (p = .001; .023; 010, respectively).

Standing. Lastly, standing was examined across the 6 to 14 month period. Standing was classified as either Supported Standing (i.e., infant was standing supporting him/herself or being supported by a caregiver) or Unsupported Standing (i.e., infant was standing without support from the hands, caregiver, or objects). To assess the quality of Supported Standing, all instances of Supported Standing in which the infant was using his/her own hands or body for support and not receiving any support from a caregiver were classified as Infant Sustained Supported Standing, and this variable was examined in a separate analysis.

Supported Standing. Developmental change in the percent of time spent in Supported Standing was analyzed first. Preliminary analyses indicated that while the intercept term (i.e., starting point) was significantly different from zero, it did not vary significantly between infants, and therefore the final conditional model included a fixed intercept term (see Table 11). As can be seen in Figure 7, the LR group started out spending approximately 4% of the session in Supported Standing. However, they increased relatively quickly, peaking at 10 months (26%), and then declining slightly by 14 months (22%).

As can be seen in Figure 7, the HR-ND group displayed a similar, although attenuated, pattern of growth to the LR infants. However, analyses indicated that the HR-ND group did not differ significantly from the LR group in growth rate or deceleration. Both the HR-LD and HR-ASD groups exhibited slower instantaneous linear growth rates than the LR group ($\beta_{1HR\text{-}LD} = -.048$, SE = .021, t = -2.298, *p* = .024; $\beta_{1HR\text{-}ASD} = -.065$, SE = .020, t = -3.278, *p* = .002), indicating that the rate of growth in Supported Standing in infants who go on to have a language delay or ASD is slowed. The HR-ASD group also did not demonstrate the decelerating pattern characteristic of the LR group ($\beta_{2HR\text{-}ASD} = .006$, SE = .003, t = 2.660, *p* = .009) and instead only exhibited linear growth. Post hoc analyses revealed that the HR-LD and HR-ASD groups diverged from the LR group as early as 8 months ($p = .009$; $p < .001$, respectively) and this difference remained significant through 14 months ($p = .010$; .007, respectively).

The HR-ASD group was not significantly different from the HR-ND or HR-LD in rate of growth for Supported Standing.

Infant Sustained Supported Standing. In order to assess change over time in the quality of Supported Standing, growth models were estimated for the percentage of time spent in Infant Sustained Supported Standing from 6 to 14 months. Preliminary analyses indicated that the intercept term (i.e., starting point) was not significantly different from zero and did not vary significantly between infants. Therefore, the intercept term was removed in the final conditional model (see, Table 11).

For the LR group, it was estimated that the percentage of time spent in Infant Sustained Supported Standing increased from 0% at 6 months to 84% by 14 months. As can be seen in Figure 8, the LR group demonstrated a slightly decelerating trajectory in which they increased relatively quickly early on and over time their rate of growth slowed. Analyses indicated that the HR-ND and HR-LD groups did not differ from the LR group on any parameter.

HR infants who were later diagnosed with ASD exhibited a delayed developmental trajectory. Specifically, relative to the LR group, the HR-ASD group had a significantly lower instantaneous linear growth rate ($\beta_{1HR\text{-}ASD}$ = -.147, SE = .055, t = -2.670, p = .009), indicating that infants who go on to have ASD initially demonstrate slowed growth in Infant Sustained Supported Standing. As a result, the percentage of time spent in Infant Sustained Supported Standing was lower for the HR-ASD group than the LR group from 8 to 12 months (p = .005; .012; 024, respectively). However, because the HR-ASD group exhibited an accelerating growth trajectory rather than a decelerating trajectory like that of the LR group ($\beta_{2HR\text{-}ASD}$ = .017, SE = .007, t = 2.592, p = .010), they caught up to their LR peers by 14 months of age (see Figure 8).

Analyses examining differences between HR-ASD infants and other HR outcome groups revealed that the HR-ASD group also differed from the HR-ND and HR-LD groups in linear growth rate (p = .011; .041, respectively) and in quadratic growth (p = .011; .029, respectively). The percentage of time spent in Infant Sustained Supported Standing was lower for the HR-ASD group than the HR-ND from 8 to 12 months (p = .019; .021; .031, respectively).

*Unsupported Standing***.** The development of Unsupported Standing was examined by estimating growth models for the percentage of time infants spent in Unsupported Standing from 6 to 14 months. Preliminary analyses indicated that the intercept term (i.e., starting point) was not significantly different from zero and did not vary significantly between infants. Therefore, the intercept term was fixed in was removed in the final conditional model (see Table 11).

As can be seen in Figure 9, it was estimated that the percentage of time in Unsupported Standing was very close to 0% from 6 to 10 months for all of the groups. The LR group demonstrated the fastest acceleration and by 14 months it was estimated that they were spending approximately 24% of the observation in the Unsupported Standing posture. The HR-ND group displayed a similar growth trajectory and did not differ from the LR infants on any parameter. While the HR-LD group exhibited slightly slower acceleration, they also did not differ significantly from the LR group.

By contrast, infants who were later diagnosed with ASD displayed significantly slower acceleration in the percentage of time spent in Unsupported Standing compared to the LR group ($\beta_{2HR\text{-}ASD}$ = -.004, SE = .001, t = -2.869, *p* = .005). The difference between the HR-ASD and LR group in the percentage of time spent in Unsupported Standing became significant by 14 months (*p* = .006). No significant differences were detected between the HR-ASD group and the HR-ND or HR-LD groups.

3.1.3 Summary

It was hypothesized that as compared to LR infants, HR infants as a group would exhibit delays in posture development. In contrast to this hypothesis, the analyses presented above indicate that overall, LR and HR-ND groups displayed similar patterns of posture development from 6 to 14 months. However, consistent with the predictions the HR-LD and HR-ASD groups exhibited initial delays in Posture Repertoire and Unsupported Sitting at 6 months. In addition, they exhibited slower growth in Supported Standing than the LR infants across the 6 to 14 month period.

A primary goal of the current study was to evaluate the extent to which delayed and/or atypical patterns of posture development may be specific to ASD by comparing HR infants with ASD to HR infants with a language delay without ASD. Analyses revealed that delays in All-4 and Infant Sustained Sitting and Standing were specific to ASD. In addition, from 10 months on, the HR-ASD infants consistently spent a greater percentage of time than typically developing infants (LR and HR-ND) and HR-LD infants in less developmentally advanced postures (i.e., Lying: 10-12 months and All-4: 14 months). The general pattern of findings that the HR-ASD group exhibited the most significant and widespread posture delays was consistent with the original hypotheses of this study.

3.2 VOCALIZATION DEVELOPMENT

The next set of HLM analyses focused on describing longitudinal trajectories of vocalization production and quality. Specifically, I examined developmental change in Total Vocalizations (i.e., Volubility) and Syllabic Vocalizations (i.e., vocalizations containing a consonant-vowel (CV) unit). As noted above, because session lengths varied slightly across individual infants, frequencies of Total Vocalizations and Syllabic Vocalizations were both converted to rates (per 10 minutes) before estimating growth models. Descriptive data are presented in Table 12 and the final model summaries are presented in Table 13.

3.2.1 Volubility

Preliminary analyses indicated that while the intercept term (i.e., starting point) for rate of Total Vocalizations was significantly different from zero, it did not vary significantly between infants, and therefore the final conditional model included a fixed intercept term (see Table 13).

As can be seen in Figure 10, at 6 months all four groups started out producing approximately 13 vocalizations per 10 minutes. The LR, HR-ND, and HR-LD infants displayed very similar patterns of growth from 6 to 14 months, with all groups gaining more than 2 vocalizations (per 10 minutes) each month. Analyses revealed that neither the HR-ND nor HR-LD infants differed significantly from the LR group in their growth rates. However, relative to the LR comparison group, the HR-ASD group grew at a significantly slower rate ($\beta_{1HR\text{-}ASD} = -1.40$, SE = .38, t = -3.707, $p < .001$). The difference between the HR-ASD and LR groups in Volubility became significant at 10 months (p <.001) and by 14 months, the level of Volubility in the HR-ASD group was approximately 1 SD below that of the LR group.

Analyses exploring differences between the HR-ASD infants and the other HR outcome groups indicated that the growth rate in Volubility for the HR-ASD group was significantly slower than that of the HR-ND group (p <.001) and the HR-LD group (p = .001). While group differences between the HR-ASD and HR-ND groups were significant at 8 months (p = .048), significant differences between HR-ASD and HR-LD infants were not observed until 10 months (p <.001).

3.2.2 Syllabic Vocalizations

Preliminary growth models for rate of Syllabic Vocalizations indicated that the intercept term (i.e., starting point) was not significantly different from zero and did not vary significantly between infants. Therefore, the intercept term was removed in the final conditional model (see Table 13). In addition, given the group differences in Volubility reported above, rate of Total Vocalizations was entered into the model as a control variable.

As can be seen in Figure 11, the rate of Syllabic Vocalizations was estimated to be zero at 6 months for all of the outcome groups. The three non-ASD outcome groups (LR, HR-ND, HR-LD) displayed almost overlapping growth trajectories from 6 to 14 months, gaining approximately 1.6 Syllabic Vocalizations (per 10 minutes) each month. Although the HR-ASD group grew at a slightly slower rate (1.4), they did not differ significantly from any of the other groups in Syllabic Vocalization production after controlling for Total Vocalizations.

3.2.3 Summary

In contrast to the predictions, the results presented here suggest that the development of Volubility across the 6- to 14-month period was comparable for the LR, HR-ND, and HR-LD groups. Never the less, as expected, the HR-ASD groups exhibited significantly slower growth in Volubility than the other three non-ASD groups. Because of their slower growth rate, the HR-ASD group became increasingly more discrepant from the other groups over time. Surprisingly, after controlling for Volubility, no differences in Syllabic Vocalization development were detected between any of the outcome groups.

3.3 RELATIONSHIP BETWEEN SITTING AND VOCALIZATION DEVELOPMENT

The second overarching goal of this research was to examine the relationship between sitting and vocalization development in HR and LR infants at 6 and 8 months of age. These age points were chosen because they represent the developmental window during which most infants achieve the Unsupported Sitting milestone and begin to produce Syllabic Vocalizations. The emergence and consolidation of the sitting posture has the anatomical consequence of opening the rib cage and allowing the head to be held in an upright position. In the sitting posture, infants can breathe more deeply, maintain subglottal pressure more consistently, and open and close their jaws more easily than in the earlier emerging lying posture. These physical changes support the production of consonant-vowel (CV) units (e.g., MacNeilage & Davis, 2000), and indeed there is some evidence that the emergence of Unsupported Sitting may actually relate to advances in Syllabic Vocalization (Yingling, 1981).

In the analyses presented below, I examined the relation between sitting and vocalization development in two ways. First, I explored whether achievement of the Unsupported Sitting milestone relates to vocalization development by comparing production of both Total Vocalizations (i.e., Volubility) and Syllabic Vocalizations at 6 months[3] across two group of infants: a) infants who were able to sit independently, without support (Sitters); and b) infants who had not yet reached this milestone (Non-Sitters). Second, I examined the interplay between sitting and vocalization production on a moment to moment timescale at 6 and 8 months by comparing rates of Total Vocalizations and Syllabic Vocalizations produced in two different postural contexts: a) Lying (i.e., Prone and Supine) and b) Sitting (i.e., Infant Sustained Supported Sitting and Unsupported Sitting)[4].

3.3.1 Questions 1: Does vocal production and quality vary as a function of unsupported sitting milestone achievement?

To address this question, rates of Total Vocalizations and Syllabic Vocalizations were compared separately for 6-month-old Sitters and Non-Sitters (see Table 14 for descriptive statistics). Medians

[3] Analyses were only performed with the 6 month data because only 5 infants had not reached the Unsupported Sitting milestone by 8 months.

[4] Caregiver Sustained Supported Sitting was excluded in order to ensure that infants were sitting in a fully upright position while in the Sitting posture context.

(Mdn) and average deviations (AD) are presented as measures of central tendency and nonparametric statistics were used (Siegel & Castellan, 1988) because inspection of the distributions indicated significant skewing and substantial individual variability.

As can be seen in Table 14, only 3 HR-LD infants and no HR-ASD infants could sit without support at 6 months. Therefore, the HR-LD and HR-ASD infants were excluded from this analysis. In addition, preliminary analyses comparing outcome groups on Total Vocalizations and Syllabic Vocalizations indicated no significant differences. Given the lack of outcome group differences and the small sample sizes, the LR and HR-ND groups were collapsed in order to increase statistical power.

Mann-Whitney *U* tests revealed that both Non-Sitters and Sitters produced similar rates of Total Vocalizations. However, Sitters produced significantly higher rates of Syllabic Vocalizations than did Non-Sitters, $p = .017$. Furthermore, an examination of the individual data revealed that 41% of Sitters but only 9% of Non-Sitters produced any Syllabic Vocalizations during the 6 month visit. A Fisher's Exact test revealed that this differences was highly significant ($p = .013$).

3.3.2 Question 2: Does vocal production and quality vary as a function of postural context?

Infants' vocalizations (i.e., rate per 10 minutes of Total Vocalizations and Syllabic Vocalizations) produced while Lying were compared to those produced while Sitting separately at 6 and 8 months (see Tables 16 and 17 for descriptive statistics). As noted above, due to significant skewing and substantial individual variability, nonparametric statistics were used for these analyses (Siegel & Castellan, 1988). Only one infant with ASD was observed in both Lying and Sitting postures at 6 months, and therefore the ASD group was excluded from the 6 month analysis. In addition, preliminary analyses comparing outcome groups on Total and Syllabic Vocalizations at 6 and 8 months indicated no significant differences between outcome groups. Given the absence of group differences and the small sample sizes, the LR, HR-ND, and HR-LD groups were collapsed in order to increase statistical power.

Wilcoxon Signed Ranks tests revealed that at 6 months, infants produced significantly higher rates of Total Vocalizations while in the Lying posture than in the Sitting posture, $p = .022$. With regard to Syllabic Vocalizations, only three infants who were observed in both Lying and Sitting postures at 6 months produced any Syllabic Vocalizations, and therefore this variable was not analyzed.

At 8 months, infants produced comparable rates of Total Vocalizations and Syllabic Vocalizations while in the Lying and Sitting postures. However, an examination of individual data revealed that 81% of infants produced more Syllabic Vocalizations while Sitting than while Lying, whereas the reverse pattern was observed in only 19% of infants. A Sign test indicated that this difference was highly significant ($p = .001$).

3.3.3 Summary

In summary, with regard to the relationship between sitting and overall vocal production, both Non-Sitters and Sitters produced similar rates of Total Vocalizations. However, an examination of the data on a moment-to-moment time scale revealed that infants produced significantly higher rates of Total Vocalizations in Lying than in Sitting posture at 6 months. By 8 months, rates of Total Vocalizations no longer varied by posture context (Lying vs. Sitting).

Turning now to the relationship between sitting and advances in vocalization quality, consistent with the hypotheses, Sitters produced significantly higher rates of Syllabic Vocalizations than Non-Sitters at 6 months. In addition, by 8 months, 81% of the infants produced more Syllabic Vocalizations while Sitting than while Lying, a distribution that is significantly different from that expected by chance. Taken together, the results indicate that not only are infants who have reached the Unsupported Sitting milestone producing more Syllabic Vocalizations than Non-Sitters, but that infants are in fact more likely to produce Syllabic Vocalizations while Sitting than Lying. These converging findings provide preliminary evidence that the development of sitting may be related to advances in vocalization quality.

4.0 DISCUSSION

The primary objectives of this research were to: a) describe posture and vocalization development in HR infants and identify group differences between LR infants and HR infants who do not receive an eventual ASD diagnosis (HR-ND and HR-LD); b) determine whether there are delays and/or deviances in posture and vocalization development that are specific to ASD (rather than an index of more general language delay); and c) examine whether sitting development relates to advances in vocalization production and quality. Findings relevant to each of these aims are discussed in turn below, followed by a brief overview of some potential clinical implications of the results and directions for future research.

4.1 POSTURE DEVELOPMENT

What is the nature of posture development in HR infants? One of the primary findings from the current study was that the HR-ND group did not exhibit posture delays compared to the LR group. This stands in contrast to previous reports of posture delays among HR infants as a group (Bhat et al., 2012; Iverson & Wozniak, 2007; Leonard et al., 2013; Nickel et al., 2013). However, these prior studies have adopted different approaches to characterizing HR infants. Some did not separate HR infants later diagnosed with ASD from those with no such diagnosis in their HR sample (e.g., Bhat et al., 2012; Iverson & Wozniak, 2007). Others did not distinguish HR infants with language delay but no ASD from those with no diagnosis (e.g., Leonard at al., 2013; Nickel et al., 2013). In light of the finding that overall the HR-ND group did not exhibit posture delays, and because children with language impairments are often significantly delayed in early posture milestones (Trauner et al., 2000; Viholainen et al., 2002), it may be particularly important to separate HR-LD infants from the larger HR group.

While trajectories of posture development were generally very similar for the HR-ND and LR groups, the HR-LD group differed substantially from the LR group and was more similar to the HR-ASD group in the development of Posture Repertoire, Supported Sitting, Unsupported Sitting, and Supported Standing. Thus, at 6 months, **both** the HR-LD and HR-ASD groups exhibited significantly smaller Posture Repertoires than the LR group. Although the HR-LD group caught up to the LR group by 8 months, the HR-ASD group did not catch up with their TD peers until 10 months. This finding generally mirrors results from Nickel et al. (2013) that HR-ASD infants exhibit a significantly smaller Posture Repertoire size in the first year than LR infants.

With regard to the development of upright postures, the HR-LD and HR-ASD infants spent significantly greater percentages of time in Supported Sitting and significantly smaller percentages of time in Unsupported Sitting than did the LR group at 6 months. The HR-ASD group exhibited the most significant delay in Unsupported Sitting, with only one infant ever observed in this posture at 6 months. In addition, the HR-LD and HR-ASD groups also displayed significantly slower growth than the LR group in time spent in Supported Standing. Since time spent performing an emergent behavior typically indexes the extent to which it is becoming well established (e.g., see Iverson & Thelen, 1999), these differences suggest that HR-LD and HR-ASD infants may have more difficulty than LR infants with maintaining balance and control in Unsupported Sitting at 6 months and Supported Standing from 8 to 14 months.

This pattern of findings emphasizes the importance of clustering HR infants into multiple categories by outcome (e.g., no concerns, language delay, ASD). Furthermore, it suggests that differences in posture development between LR and HR groups reported previously may be driven by subgroups of infants with ASD or who have a non-ASD language delay. Given the overall lack of differences between the LR and HR-ND groups, the current study highlights the fact that being at "heightened risk" (i.e., having an older sibling with ASD) is not synonymous with manifesting delays or autism symptomatology.

Are there delays and/or deviances in posture development that are specific to ASD? HR-ASD infants exhibited distinct trajectories in All-4, Lying, Infants Sustained Sitting, and Infants Sustained Standing that did not parallel those of the TD infants (LR and HR-ND) or the HR-LD infants. Specifically, the HR-ASD group spent significantly smaller percentages of time in the All-4 posture from 8 to 10 months as compared to the other three groups. By 14 months, the HR-ASD group was spending a significantly greater percentage of time in the All-4 posture than each of the non-ASD groups (LR, HR-ND, and HR-LD) and a significantly smaller percentage of time in Unsupported Standing than the LR group. The development of Lying also differentiated the HR-ASD group from all of the other groups. While time spent Lying generally declined from 6 to 14 months, the HR-ASD group continued to spend a significantly greater percentage of time than non-ASD infants in this early emerging, less developmentally advanced posture at 10 and 12 months.

In the current study, Supported Sitting and Supported Standing postures were further classified as either Infant Sustained (i.e., an infant holding him or herself up using the hands or body but not receiving any support from the caregiver) or Caregiver Sustained. Infant Sustained Sitting and Standing can be thought of as intermediate postures en route to the development of

Unsupported Sitting and Unsupported Standing because they are not as biomechanically challenging as unsupported postures, but they require greater postural control than do caregiver sustained postures. Growth models were estimated for the percentages of time spent in Supported Sitting and Supported Standing that was Infant Sustained. From 6 to 14 months, all of the groups increased in infant sustainment. However, compared to all three non-ASD groups, the HR-ASD infants exhibited significant delays in both Infant Sustained Sitting and Standing postures. Therefore, the HR-ASD infants in the current study were not only delayed in the more biomechanically challenging unsupported postures, but they even struggled with the relatively less demanding infant sustained supported postures. Given that in the present study the reciprocal of infant sustainment was caregiver sustainment, it can be inferred that the HR-ASD infants were spending a proportionally greater amount of time in supported postures being sustained by a caregiver than non-ASD infants.

There is substantial research on TD infants indicating that the skills required to sustain Unsupported Sitting and Standing postures consolidate relatively slowly and only after an extended period in which infants practice sustaining themselves using their arms and hands for support (e.g., see Adolph & Berger, 2005). The variability in movement that is created when infants sustain themselves in supported upright postures provides important opportunities for exploration of the boundaries within which they can remain stable (Dusing & Harbourne, 2010). Similarly, with progressive control in Infant Sustained Supported Sitting, infants can flexibly assume many different positions. Caregiver Sustained Supported Sitting may reduce opportunities for varied movements and result in infants getting stuck in simple and repetitive movement patterns (Dusing, Kyvelidou, Mercer, & Stergiou, 2009; Thelen, 2004). In addition, before infants have mastered Unsupported Sitting and Unsupported Standing milestones, they frequently topple over when lifting their hands off a supportive surface to reach for objects and people in their environments. Research suggests that practice with falling in a variety of situations provides invaluable learning that leads to adaptive control of motor actions (Adolph et al., 2012; Joh & Adolph, 2006). Thus, decreased time in Infant Sustained Supported Sitting and Supported Standing may not only negatively affect the building of muscle strength and balance; it may also limit valuable opportunities for integrating vestibular and proprioceptive information with ongoing motor activity to control postural sway.

Taken together, the general pattern of results is consistent with the growing body of prospective research on motor development in infants eventually diagnosed with ASD suggesting that very early delays in posture milestones are among the earliest identifiable disruptions in the unfolding of the disorder (e.g., Estes et al., 2015; Flanagan, Landa, Bhat, & Bauman, 2012; Leonard et al., 2013; Nickel et al., 2013). The present investigation also extends prior work by including a comparison HR-LD group, which permitted the identification of delays that may be specific to ASD. Findings provide initial evidence that delays in the development of postural control may be more pronounced and widespread for HR-ASD infants than HR-LD infants and that subtle differences in posture development in the first year may help to differentiate these two groups.

Cascading effects of posture development and delay. There is longstanding evidence from developmental research indicating that advances in posture naturally afford infants broader and more diverse opportunities for engaging with people and objects in the environment in ways that are increasingly sophisticated. For example, the emergence of Unsupported Sitting allows infants to have their hands free to manipulate objects and bring them into a relatively stable field of vision (e.g., Rochat & Goubet, 1995). In comparison to infants who cannot yet sit alone, selfsitting infants more frequently explore objects manually while looking at them (Soska, Adolph, & Johnson, 2010). An increasing ability to reach for and grasp varied objects, coupled with a shift in attentional focus towards the objects themselves, serves as a signal to caregivers to introduce novel play routines with objects that involve language and communication tailored to the infants' focus of attention (Fogel, 1990). Thus, with the development of Unsupported Sitting, object-focused attention is increasingly embedded in social contexts in which caregivers scaffold their infants' developing ability to share attention with objects and people (Bakeman & Adamson, 1984). Not only does the development of independent sitting change infants' experiences with their environment, but it also results in new upright head and trunk positions that have implications for infant vocalizations (see below for further discussion).

The All-4 and Standing postures set the stage for the emergence of crawling and walking, respectively. Independent locomotion is a dramatic achievement that fundamentally alters infants' experiences with the world. For example, crawling allows infants, for the first time, to independently access new objects and conditions in their environment while at a distance from their caregivers. In turn, caregivers respond by increasing their communication about distally located objects, often to regulate their infants' behavior (Zumbahlen, 1997). It is principally after crawling that infants begin to receive social signals from a distally located caregiver that has a clear distal referent. This experience is fundamental to the emergence of pointing. Thus, it is not surprising that crawling infants are more successful at following adult pointing towards a distal target than same age prelocomotor infants (for whom communication is typically from a proximal caregiver and about a proximal event; Campos et al., 2000).

The transition from crawling to walking provides infants with an elevated vantage point and frees their hands from having to support the body. These changes make it easier for infants to locate caregivers and travel to them while transporting an object of interest, which naturally affords them a more active role in initiating communicative exchanges. Indeed, relative to 13-month-old crawling infants, same-aged walking infants more frequently accessed distally located objects and initiated object sharing by carrying an object and moving toward a parent (Karasik, Tamis-LeMonda, & Adolph, 2011). Because walking infants can easily find distal objects of interest and bring them directly to their caregivers, even if their caregivers are not attending to them or are in another room, these 'moving bids' may be particularly salient and highly likely to elicit a response from caregivers. This has important implications for language development because caregivers often respond to infants' communicative bids with objects by providing a label for the object (Golinkoff, 1986; Masur, 1982). Moments of this sort – in which the word to be acquired is provided while the child's attention is actively focused on its referent – are optimal for word learning (Tomasello & Farrar, 1986).

One implication of this framework is that delays in posture development may have negative cascading effects on development outside the motor domain (e.g., object exploration, vocalizations, language, and social communication behaviors). Consider the case of the HR-ASD infants, who as a group exhibited widespread delays in posture development. Difficulties with postural control well into the second half of the first year likely make it more difficult for HR-ASD infants to reach for and manipulate objects while trying to maintain stability and balance. As a result, caregivers may have fewer opportunities to comment on objects the infant is attending to and reaching toward. In addition, caregivers may need to use their hands to support the infant, which will likely make bringing objects into play routines more challenging. A decrease in object-focused attention embedded in social contexts could negatively impact the development of social communication and language by limiting caregivers' opportunities for scaffolding joint attention and providing linguistic input about objects that are linked to the infants' immediate focus of attention. The ultimate outcome of this cascade may be that the infant who is delayed in posture development may become a toddler delayed in the development of social communication and language.

The consequences of even minor motor disruptions for future social communication and language development may be particularly far-reaching for infants with ASD, who experience delays and/or deficits across a variety of domains, because alternative developmental pathways for acquiring new behavioral patterns may be narrowed (Thelen, 2004). Studies of HR infants are beginning to demonstrate that posture delays in the first year is a good predictor of future language and communication skill in infants eventually diagnosed with ASD (e.g., Leonard et al., 2015). Although conclusions regarding the causal nature of these relations are premature, further investigations examining the link between motor and communication development in this population will be important for understanding mechanisms of both typical and atypical development.

4.2 VOCALIZATION DEVELOPMENT

What is the nature of vocalization development in HR infants? Turning now to vocalization development, longitudinal trajectories of Volubility (total vocalizations, excluding non-speech vegetative and affective sounds) and Syllabic Vocalizations were modeled from 6 to 14 months across the four groups of infants. Analyses revealed that LR, HR-ND, and HR-LD infants exhibited very similar patterns of Volubility and Syllabic Vocalization development, with all three groups exhibiting increased production over time. The HR-ASD group exhibited significantly slower growth in Volubility than all three of the non-ASD groups. However, there were no significant between-group differences in Syllabic Vocalization development after controlling for overall Volubility.

In the only other infant sibling study to date reporting detailed analyses of pre-speech vocalization development, Paul et al. (2011) reported that relative to LR infants, HR infants as a group produced fewer Total Vocalizations (excluding non-speech vegetative sounds) at 6, 9, and 12 months and a smaller percentage of Canonical Syllables at 9 months. It is difficult to compare these findings with the current study because Paul et al. (2011) did not separate HR infants later diagnosed with ASD from those with no such diagnosis in their HR group. Given the lack of differences between LR and HR non-ASD groups in the current study, findings reported by Paul et al. (2011) may be due to the subgroup of infants with ASD in the HR group (presumably 20% of their HR sample).

Are there delays and/or deviances in vocalization development that are specific to ASD? The finding that HR-ASD infants exhibited significantly slower growth in Volubility than HR-LD infants, together with the absence of reduced Volubility in the HR-LD group, suggests that decreased Volubility may be specific to ASD rather than an index of more general language delay. Low volubility in the HR-ASD group as compared to controls is consistent with prior research on young children with ASD (Warren et al., 2010) as well as with a retrospective video study of infants with ASD (Patten et al., 2014). However, with the inclusion of a language-delayed group, the present study extends prior work and allowed identification of delays potentially specific to ASD. In addition, the Warren et al. (2010) study was cross-sectional, and the Patten et al. (2014) study only reviewed videos from two age points (9-12 months and 15-18 months). Because the current study observed infants prospectively and longitudinally at five age points, it was possible to provide a much more complete developmental picture of change over time in Volubility among infants eventually diagnosed with ASD than was previously available.

The lack of significant outcome group differences in the development of Syllabic Vocalization was unexpected. It stands in contrast to prior research indicating that production of syllables is significantly reduced among young children with ASD (Oller et al., 2010), infants eventually diagnosed with ASD (Patten et al., 2014), and HR infants (Paul et al., 2011) compared to TD comparison groups. A potential explanation for this difference may have to do with how Syllabic Vocalizations were coded. In the present study, non-word vocal utterances were classified as Syllabic if they contained at least one consonant-vowel (CV) syllable. Thus, vocal utterances containing one syllable [ba] and vocal utterances containing several syllables [babababa] were both coded as **one** Syllabic Vocalization. In contrast, Patten et al. (2014) and Paul et al. (2011) coded each CV syllable separately, and therefore a vocal utterance such as [babababa] would have been coded as **four** separate Syllabic Vocalizations instead of only one. It is possible that non-ASD infants increase more quickly than ASD infants in the production of multisyllabic vocalizations over time (Fagen, 2009). However, this difference would be masked in the current study because we only coded the presence/absence of Syllabic Vocalizations, not the number of CV units within the Syllabic Vocalization. Taken together, this suggests that the more global method utilized for coding Syllabic Vocalizations in the current study may not be sensitive enough to detect potentially subtle differences in vocal quality among infants eventually diagnosed with ASD.

Cascading effects of vocal development and delay. Long before language emerges, infants produce vocalizations that become increasingly complex and more speech-like over time. From the first few months of life, infant vocalizations play an integral role in infant-caregiver social interactions. The production of pre-linguistic vocalizations is one of the earliest ways in which infants alter the availability of opportunities for learning that support subsequent development.

Although very early pre-linguistic vocalizations are often not produced with communicative intent on the part of the infant (i.e., not directed towards a social partner), caregivers still respond to these vocalizations contingently (e.g., Snow, 1977). Contingent social responses to pre-linguistic vocalizations help infants learn about the consequences of their behaviors and acquire an understanding of the contingencies defining more complex communicative interaction (Goldstein, Schwade, & Bornstein, 2009). Furthermore, maternal contingent responsiveness to infant pre-linguistic vocalizations has been shown to be a robust predictor of expressive language development in the second and third year (Tamis-LeMonda, Bornstein, & Baumwell, 2001).

The variability observed in maternal responsiveness to infant vocalizations is not only reflective of maternal agency, but also reflects infant agency and the dyadic interplay between infant and caregiver that constitutes their past and present experiences. As Snow (1986) noted,

> Mothers are able to provide children with semantically relevant and interpretable speech because they follow up on topics introduced by the child. It seems that some mothers will be better at doing this than others, but also that some children will be better at eliciting semantically relevant and interpretable speech than others (p. 86).

Evidence supporting this view has demonstrated that mothers respond differentially to vocalizations that vary in quality (Gros-Louis, West, Goldstein, & King, 2006). Specifically, mothers responded with imitations to developmentally advanced Syllabic Vocalizations significantly more often than to earlier emerging vowel-like sounds. Prior research has shown that particular types of maternal contingent responses, such as imitations, correlate positively with language development (Girolametto, Weitzman, Wiigs, & Pearce, 1999; Tamis-LeMonda et al., 2001).

Infant object-directed vocalizations (ODVs; Goldstein et al., 2010a) also appear to provide valuable opportunities for interactions that advance word learning. Caregivers frequently respond to ODVs by labeling the object to which the infant is attending. As noted above, this type of occurrence, in which the target word is provided while the child's attention is actively focused on its referent, is optimal for word learning (e.g. Tomasello and Farrar, 1986). Indeed, longitudinal work has demonstrated that adult responsiveness to the ODVs of 9 month-old infants predicted vocabulary size at 15 months (Goldstein & Schwade, 2010). These findings indicate that infants create opportunities for socially guided learning through vocalizations, perhaps by signaling to caregivers a readiness to acquire linguistic information about their world.

Taken together, there is compelling evidence that advances in infant pre-speech vocalizations engender changes in caregivers' social and linguistic responses that support future social communication and language skills. Social communication and language deficits are characteristic of ASD. Given the existing work that has examined the impact of pre-linguistic vocalization development on the learning environment, it seems likely that early emerging disruptions may have negative cascading effects on later social, communication, and language development for these children.

Evidence from the current study, along with other research, indicates that from a very early age (at least 8 months) infants eventually diagnosed with ASD exhibit significantly decreased Volubility relative to TD infants and infants eventually classified as language delayed. A significant decrease in infant-initiated vocalizations will, in turn, limit caregivers' opportunities for providing responses. Caregiver contingent responses scaffold pre-linguistic skills and relate to later advances in language and communication. Although the current study did not find differences between outcome groups in the quality of vocalizations after controlling for Volubility, the nature of low Volubility means that infants will have fewer opportunities to produce vocalizations of all types. In other words, because ASD infants are vocalizing less overall, we can assume that they are also producing fewer of the types of vocalizations that are most likely to elicit rich verbal input (e.g., Syllabic and ODVs). Thus, a potentially significant consequence of low Volubility is that caregivers may have fewer opportunities to provide input that is particularly important for language and communication development.

Decreased volubility may not only change the nature of input that infants receive from the environment, but may also influence opportunities for infants to coordinate vocalizations with other communicative behaviors. Given decreased Volubility in infants later diagnosed with ASD, it is not surprising that delays in vocalizations coordinated with gestures have been document during the second year in this population (Parladé & Iverson, 2015). The production of communicative coordinations, such as gesture-vocalization coordinations, is a particularly important social communicative skill because it allows infants to provide a clear signal of intentional communication to their social partner.

4.3 RELATIONSHIP BETWEEN SITTING AND VOCALIZATION DEVELOPMENT

Much of the research examining how motor development sets the stage for later acquisitions has focused on ways in which the developing motor system affords experiences with the environment that support emerging development outside the motor domain (e.g., Campos; 2000). However, the emergence of new postures also changes infants' experiences with their own bodies in ways that create altered opportunities for exploration and expansion of skills not specific to the motor domain. A prime example of this is Unsupported Sitting, which has the anatomical consequence of opening the rib cage and allowing the head to be held in an upright position. As described in more detail above, both of these changes support the production of Syllabic Vocalizations like those produced in babbling (e.g., [babababa]).

The present study examined the interplay between sitting development and advances in vocalization production and quality (i.e., Syllabic Vocalizations) in LR, HR-ND, HR-LD, and HR-ASD infants. Findings indicated that infants produced significantly higher rates of Total Vocalizations while in the Lying posture (Prone + Supine) than while in the Sitting posture (Infant Sustained Supported Sitting + Unsupported Sitting) at 6 months. However, the rate of Total Vocalizations no longer varied by posture context by 8 months. One interpretation of these findings is that vocalizing while sitting at 6 months is particularly challenging because infants are only beginning to develop the skills necessary for Unsupported Sitting and therefore they must exert substantial cognitive and physical resources to maintain sitting without toppling over. Along these lines, there is a long-standing, widespread, but empirically unverified belief among pediatricians, parents, and even some developmental scientists that that when infants are first acquiring a new motor skill (e.g., walking), their language comes to halt (see Tipps, Mira & Cairns, 1981). If it is the case that performing a new motor skill makes it more difficult for infants to engage in other behaviors, then it is not surprising that rate of Total Vocalizations differed by posture at 6 months but not at 8 months.

Turning now to the interplay between sitting and advances in vocalization quality, findings revealed that Sitters (i.e., infants who had reached the Unsupported Sitting Milestone at 6 months) produced significantly higher rates of Syllabic Vocalizations than Non-Sitters (i.e., infants who had not yet reached the Unsupported Sitting Milestone at 6 months). In addition, infants produced significantly more Syllabic Vocalizations in Sitting than in Lying. Thus, not only are infants who have reached the Unsupported Sitting milestone producing more Syllabic Vocalizations than Non-Sitters, but infants are in fact more likely to produce Syllabic Vocalizations while in the Sitting posture than the Lying posture. These findings are consistent with prior research demonstrating that development in Unsupported Sitting relates to advances in Syllabic Vocalizations (Yingling, 1981).

The present study extends previous work with TD infants by including a group of HR infants. The pattern of findings suggests that the effect of sitting development on changes in vocal production and quality is similar for LR, HR-ND, and HR-LD infants. It was not possible to include the HR-ASD infants in these analyses because so few were able to sit alone at 6 months. However, as described above, relative to the comparison groups, the HR-ASD infants exhibited significant delays in both Infant Sustained Supported Sitting and Unsupported Sitting postures, and they spent more time in the Lying posture at later ages. To the extent that Sitting creates a more supportive context for producing CV units than does Lying, infants with ASD (and to a lesser extent, infants with LD) may have fewer opportunities to produce Syllabic Vocalizations than non-posture delayed infants. A simple reduction in the act of producing these vocalizations may limit infants' opportunities for receiving proprioceptive and auditory feedback that leads to continued vocal exploration and the development of more complex sounds.

4.4 CLINICAL IMPLICATIONS

The importance of the early identification of ASD has been underscored by evidence that early behavioral intervention for very young children with the disorder can diminish symptoms and significantly improve developmental outcomes (e.g., Dawson et al., 2010). Furthermore, research from the Autism Society estimates that the lifetime cost of caring for an individual with autism ($3.5-5 million) can be reduced by two-thirds or more with early diagnosis and intervention (Autism Society, 2007). Thus, the effects of undiagnosed or misdiagnosed children are great, both on the emotional and economic well-being of the families as well as the cost for society.

The results reported here have implications for developmental screening that may be relevant to the early identification of ASD. First, they indicate the importance of considering broad patterns of delays in **both** posture and vocalization development, particularly during the first year, in infants at heightened risk for ASD. The majority of early screening measures for ASD focus on social-communicative behaviors that do not emerge until the second year, even in typical development (e.g., Robins, Fein, Barton, & Green, 2001. Although it is not practical to code behavior frequencies and durations of posture and vocal behaviors during medical office visits, these results suggest that it may be possible to develop measure that can be rated by physicians or nursing staff during well-child visits that capture additional information about an infant's skills in these areas. However, more research is necessary to refine the process by which behavior is coded in a way that would be feasible outside of the laboratory.

Second, the present findings highlight the importance of tracking behavior over time rather than focusing on delays in single milestones. This was particularly apparent from the growth trajectories of posture development. For example, with All-4 development the HR-ASD infants exhibited a different shape of change over time in this posture. Whereas all three comparison groups exhibited quadratic growth in which there was an increase from 6 to 10 month and followed by a decrease, the HR-ASD group exhibited only linear growth. In other words, the HR-ASD infants did not just exhibit a delay in All-4 (i.e., consistently less time in All-4 at each age point), but they followed an alternate route of development. This suggests that evaluating an infant's ability to perform a specific posture at one age point may be less informative than tracking their development longitudinally.

Finally, this study provides initial evidence that compared to language-delayed infants, infants with ASD exhibit more widespread delays in posture development and decreased volubility starting at 8 months. However, future research is needed to delineate aspects of posture and vocal delays that may be specific to ASD relative to other high risk populations. For example a high percentage of infants from lower socio-economic status (SES) homes exhibit decreased volubility compared to middle or high SES infants (Eilers et al., 1993; Oller, Eilers, Basinger, Steffens, & Urbano, 1995). In, addition, delayed motor development is commonly observed in preterm infants (e.g., Ungerer & Sigman, 1983; Van Haastert, De Vries, Helders, & Jongmans, 2006). Nevertheless, given the importance of skilled movement and vocalization production for social communication, language, and cognition (Iverson, 2010; Thelen, 2004), identifying such delays and providing appropriate intervention at an early age is critical.

Posture and vocalization skills are developmentally appropriate and relatively straightforward targets for early intervention. Identifying and intervening with infants who have early motor and/or vocal delays may be particularly important because achievements in these domains transform infants' earliest experiences. Currently, intervention programs for infants exhibiting early signs of ASD focus on skills that promote affective social engagement and reciprocity and do not address motor or vocal disruptions (Dawson et al., 2010; Rogers & Dawson, 2010). However, it may be useful, within these broader early intervention models, to consider ways in which improvements in postural stability and vocalization production can set the stage for enhancement of social communication and language development.

The present study provides further support to the view that we should no longer be thinking about posture and vocalization skills as discrete, isolated behaviors. Instead of focusing on improving motor skills (e.g., muscle strength, balance, and range of motion) or vocalization production in isolation, it will likely be more effective to focus on broadly enhancing the infant's capacity for exploratory experiences and emphasizing the bidirectional influence of the infant and caregiver across time. Such interventions might include providing caregivers with information about the potential developmental importance of postural stability for exploration of objects as well as social interactions. In addition, as described above, reduction in pre-linguistic vocalizations gives caregivers fewer opportunities to provide contingent responses, which have been shown to scaffold prelinguistic skills (e.g., growth in caregiver-directed vocalizations; Gros-Louis et al., 2014) and relate to later advances in language (e.g., vocabulary growth; e.g., Tamis-LeMonda, Bornstein, & Baumwell, 2001). Thus, clinicians may consider heightening caregiver attention to infant vocalizations and encouraging them to provide contingent responses, regardless of the developmental level and/or social salience of the vocalizations.

4.5 GENERAL CONCLUSIONS

Taken together with the larger literature, we can conclude that the unfolding of ASD likely involves very early disruptions in postural control and vocal production. This is followed by the more defining behaviors of ASD (e.g., delayed and/or atypical social-communication and language development, lack of pretend play, poor reciprocal social interactions) that begin to emerge at the end of the first year and are increasingly evident over the second and third years. The current study is the only prospective and longitudinal study to date examining posture and vocalization development among infants at risk for ASD. Furthermore, it is among the first studies to include a comparison group of HR-LD infants. Given that researchers have struggled to identify observable and behavioral differences between ASD and non-ASD groups prior to 12 months of age, the findings from the current study make a substantial contribution to the field.

Very rarely has the interplay between motor and communication development been studied in children with ASD despite the longstanding history of this type of research with TD infants. The present study is among the first attempts to understand the cascading effects of very early posture delays for subsequent vocalization development in infants at risk for ASD. The underlying mechanisms involved in the emergence and development of the core features of ASD (i.e., disruptions in language and communication and reciprocal social interactions) cannot be fully understood by dissecting development into constituent parts because the individual components and their associated functions are dynamically embedded within the context of the system that is the developing infant (Thelen & Smith, 1994). Accordingly, deepening our understanding of the phenomena involved in the unfolding of ASD will require investigations of multiple modalities as they interact and evolve in the natural environment over time

Future research is needed examining posture and vocalization development as well as the interplay between these domains with larger samples. We know from decades of research that ASD is an extremely heterogeneous and complex disorder. Thus, future work with larger ASD groups should focus on examining relationships between individual differences in patterns of delays in posture and vocalization development during the first year and symptom severity rather than just the presence or absence of an ASD diagnosis. In addition, research on mechanisms underlying posture and vocalization delays in infants with ASD awaits future investigation. A critical next step will be collection of kinematic data that permit the examination of postural sway and stability in a way that behavioral coding of posture duration cannot. Over the past few years, there has been rapid growth in the development of technologies (e.g., LENA system) that can automatically classify vocalizations of infants and caregivers during all-day recordings. Such methodologies have potential to provide important insights into how decreased volubility in infants with ASD may affect the broader social environment.

5.0 TABLES

Table 1: Demographic Information for High Risk and Low Risk Group

	HR (n = 59)		LR (n = 25)	
Gender				
Female (%)	30	(51%)	15	(60%)
Male (%)	29	(49%)	10	(40%)
Racial or Ethnic Minority	7	(12%)	1	(4%)
Birth Order				
First Born (%)	0	(0%)	9	(36%)
Later Born (%)	59	(100%)	16	(64%)
Mean age for Mothers (SD)	34.08	(4.41)	31.92	(4.95)
Mean age for Fathers (SD)	35.81	(4.19)	33.08	(4.08)
Maternal Education				
High School (%)	5	(8%)	1	(4%)
Some College or College Degree (%)	37	(63%)	10	(40%)
Graduate or Professional School (%)	17	(29%)	14	(56%)
Paternal Education				
High School (%)	4	(7%)	3	(12%)
Some College or College Degree (%)	32	(54%)	13	(52%)
Graduate or Professional School (%)	21	(36%)	9	(36%)
Mean Paternal Occupational Prestige (SD)[a]	57.50	(16.20)	55.21	(14.41)

Note. HR = High Risk; LR = Low Risk

[a]Nako-Teas occupational prestige score; not able to be calculated for 3 fathers in HR group and 2 fathers in LR group.

Table 2: Mean Standardized Scores at 36 months for the HR Outcome Groups

	HR-ND (*N* = 28)		HR-LD (*N* = 17)		HR-ASD (*N* = 14)	
	M	*SD*	*M*	*SD*	*M*	*SD*
MSEL Visual Reception T Score	58.14[a]	14.22	51.71[a]	15.10	29.70[b]	12.95
MSEL Fine Motor T Score	50.71[a]	14.06	42.59[a]	14.26	26.00[b]	7.30
MSEL Receptive Language T Score	54.75[a]	9.29	44.41[b]	7.96	27.30[c]	10.40
MSEL Expressive Language T Score	110.57[a]	17.50	94.29[b]	14.71	64.67[c]	14.82
ADOS Severity Index	1.65[a]	1.47	1.80[a]	1.15	6.62[b]	2.06

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder; MSEL = Mullen Scales of Early Learning; ADOS = Autism Diagnostic Observation Schedule. All children received either Module 1 (n = 8) or Module 2 (n = 46) based on their expressive language level at the time of the assessment.

Differing subscripts show significant differences between groups as indicated by pairwise comparisons using the Bonferroni correction.

Table 3: Definitions of Posture Types

Posture	Definition
Lying	
Lying	Lying on the stomach or on the back
Sitting	
Supported Sitting	Seated with support from the caregiver, hands, or body (e.g., sitting on couch and receiving back support from the couch)
Unsupported Sitting	Seated without support from the caregiver, hands, or body
All-Four	
All-4	On hands and knees
Standing	
Supported Standing	Standing with support from the caregiver, hands, or body (e.g., leaning against the wall for support)
Unsupported Standing	Standing without support from caregiver, hands, or body

Table 4: Number of Infants (n) with Available Data at 6, 8, 10, 12, and 14 Months by Outcome Group and Type of Coding (Posture and Vocalization)

	LR		HR-ND		HR-LD		HR-ASD	
	Posture	Voc.	Posture	Voc.	Posture	Voc.	Posture	Voc.
	n	*n*	*n*	*n*	*n*	*n*	*n*	*n*
6 Months	24	25	22	24	15	15	8	8
8 Months	24	25	27	27	14	13	9	9
10 Months	24	25	27	26	16	15	14	14
12 Months	24	24	28	28	16	15	14	14
14 Months	25	25	28	28	16	16	13	13

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 5: Mean Number (M), Standard Deviations (SD), and Ranges of Posture Repertoire at 6, 8, 10, 12 & 14 months by Outcome Group

	LR			HR-ND			HR-LD			HR-ASD		
	M	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
6 Months	3.13	1.33	4.00	2.64	1.22	5.00	2.00	1.00	4.00	2.13	.83	2.00
8 Months	4.33	1.52	6.00	4.19	1.33	7.00	3.71	1.33	5.00	3.00	.87	2.00
10 Months	5.63	1.81	7.00	5.44	1.78	7.00	5.38	1.63	5.00	5.57	2.14	6.00
12 Months	6.96	1.04	3.00	6.36	1.75	6.00	6.38	1.41	5.00	6.21	1.31	4.00
14 Months	7.12	.88	3.00	6.75	1.43	6.00	7.00	1.21	4.00	7.08	.86	2.00

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 6: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Posture Repertoire

	Posture Repertoire	
	Coefficient	SE
Intercept 6 months		
Intercept β_{00}	3.049***	0.273
Male	0.417	0.275
HR-ND	-0.365	0.351
HR-LD	-1.069**	0.394
HR-ASD	-1.140**	0.403
Growth Rate		
Intercept β_{10}	0.823	0.168
Male	-0.104	0.166
HR-ND	0.024	0.220
HR-LD	0.236	0.236
HR-ASD	0.165	0.283
Acceleration/Deceleration		
Intercept β_{20}	-0.038	0.019
Male	0.007	0.018
HR-ND	-0.004	0.024
HR-LD	-0.016	0.026
HR-ASD	-0.005	0.031
Variance Components		
Intercept (r_{0i})	0.671***	
Linear Growth (r_{1i})	0.354***	
Quadratic Growth (r_{21})	0.004***	
Level 1 Error (e_{ti})	0.855	
Parameters (FIML)	7	
Deviance (FIML)	1287.301	

*p < .05. **p < .01. ***p < .001.

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 7: Mean Percentage (M), Standard Deviations (SD), and Ranges of Posture Durations at 6, 8, 10, 12 & 14 months by Outcome Group

	LR			HR-ND			HR-LD			HR-ASD		
	M	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
6 Months												
Lying	0.40	0.32	0.98	0.37	0.23	0.86	0.39	0.34	1.00	0.42	0.27	0.84
Supported Sit	0.26	0.23	0.91	0.35	0.23	0.93	0.44	0.29	0.81	0.46	0.20	0.66
Infant Sit	0.31	0.38	1.00	0.24	0.28	0.86	0.23	0.29	0.94	0.07	0.08	0.19
Unsupported Sit	0.23	0.31	0.95	0.13	0.22	0.80	0.10	0.23	0.82	0.00	0.01	0.02
All-4	0.02	0.05	0.22	0.04	0.09	0.37	0.00	0.01	0.05	0.00	0.01	0.02
Supported Stand	0.06	0.11	0.36	0.06	0.06	0.21	0.03	0.03	0.10	0.02	0.04	0.09
Infant stand	0.13	0.31	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unsupported Stand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 Months												
Lying	0.09	0.15	0.60	0.13	0.21	0.98	0.18	0.19	0.65	0.18	0.28	0.88
Supported Sit	0.17	0.15	0.65	0.19	0.13	0.55	0.24	0.19	0.64	0.35	0.24	0.64
Infant Sit	0.57	0.35	1.00	0.52	0.38	1.00	0.47	0.30	1.00	0.19	0.23	0.57
Unsupported Sit	0.45	0.27	0.86	0.40	0.27	0.94	0.41	0.28	0.96	0.39	0.29	0.78
All-4	0.12	0.12	0.36	0.15	0.16	0.54	0.07	0.09	0.25	0.04	0.08	0.23
Supported Stand	0.16	0.17	0.60	0.10	0.11	0.48	0.08	0.13	0.47	0.04	0.04	0.11
Infant stand	0.42	0.42	1.00	0.26	0.38	0.98	0.12	0.29	0.97	0.00	0.00	0.00
Unsupported Stand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 Months												
Lying	0.02	0.04	0.20	0.04	0.08	0.37	0.02	0.03	0.13	0.15	0.26	0.87
Supported Sit	0.16	0.09	0.41	0.14	0.07	0.24	0.19	0.11	0.41	0.16	0.11	0.40
Infant Sit	0.72	0.28	1.00	0.65	0.33	1.00	0.67	0.26	0.80	0.64	0.34	1.00
Unsupported Sit	0.33	0.18	0.71	0.46	0.21	0.80	0.51	0.19	0.73	0.47	0.24	0.93
All-4	0.14	0.10	0.41	0.11	0.10	0.38	0.15	0.09	0.30	0.11	0.08	0.29

Supported Stand	0.26	0.17	0.62	0.18	0.19	0.53	0.12	0.11	0.36	0.08	0.08	0.28
Infant stand	0.68	0.35	1.00	0.70	0.28	1.00	0.56	0.33	0.98	0.53	0.32	0.96
Unsupported Stand	0.02	0.06	0.22	0.02	0.05	0.27	0.01	0.02	0.07	0.00	0.00	0.01
12 Months												
Lying	0.02	0.02	0.10	0.02	0.02	0.10	0.02	0.03	0.10	0.05	0.07	0.26
Supported Sit	0.19	0.16	0.53	0.16	0.10	0.37	0.21	0.12	0.49	0.20	0.10	0.40
Infant Sit	0.64	0.34	0.96	0.68	0.31	0.95	0.61	0.35	0.98	0.62	0.31	0.96
Unsupported Sit	0.28	0.17	0.57	0.40	0.26	0.95	0.33	0.18	0.63	0.37	0.19	0.61
All-4	0.08	0.05	0.18	0.08	0.08	0.28	0.09	0.06	0.22	0.08	0.08	0.31
Supported Stand	0.23	0.21	0.82	0.18	0.18	0.63	0.18	0.13	0.52	0.15	0.13	0.46
Infant stand	0.64	0.35	1.00	0.73	0.33	1.00	0.74	0.29	1.00	0.48	0.41	0.96
Unsupported Stand	0.10	0.13	0.46	0.10	0.13	0.45	0.07	0.13	0.38	0.08	0.13	0.44
14 Months												
Lying	0.02	0.02	0.06	0.02	0.02	0.08	0.03	0.05	0.16	0.03	0.05	0.14
Supported Sit	0.14	0.10	0.38	0.14	0.09	0.37	0.20	0.12	0.46	0.18	0.10	0.31
Infant Sit	0.25	0.16	0.63	0.27	0.18	0.75	0.29	0.18	0.66	0.36	0.15	0.57
Unsupported Sit	0.69	0.32	0.94	0.72	0.26	0.87	0.77	0.26	0.88	0.72	0.28	0.89
All-4	0.04	0.04	0.17	0.08	0.09	0.41	0.06	0.06	0.23	0.12	0.05	0.17
Supported Stand	0.23	0.12	0.51	0.17	0.12	0.45	0.13	0.07	0.25	0.12	0.08	0.23
Infant stand	0.90	0.12	0.41	0.77	0.28	1.00	0.72	0.27	0.99	0.80	0.19	0.60
Unsupported Stand	0.25	0.15	0.57	0.22	0.20	0.73	0.17	0.14	0.40	0.10	0.10	0.28

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder
For the six main posture categories (Lying, Supported Sitting, Unsupported Sitting, All-4, Supported Standing, and Unsupported Standing) total time was used as the denominator when calculating percentages.
For Infant Sustained Supported Sitting (Infant Sit) and Infant Sustained Supported Standing (Infant Stand) time spent in Supported Sitting or Supported Standing was used as the denominator when calculating percentages.

Table 8: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Lying

	Lying	
	Coefficient	SE
Intercept 6 months		
Intercept β_{00}	0.364***	0.054
Male	-0.082	0.063
HR-ND	-0.031	0.071
HR-LD	0.024	0.095
HR-ASD	0.022	0.105
Growth Rate		
Intercept β_{10}	-0.138***	0.022
Male	0.030	0.025
HR-ND	0.028	0.030
HR-LD	0.006	0.038
HR-ASD	0.048	0.043
Acceleration/Deceleration		
Intercept β_{20}	0.012***	0.002
Male	-0.002	0.002
HR-ND	-0.003	0.003
HR-LD	-0.001	0.004
HR-ASD	-0.006	0.004
Variance Components		
Intercept (r_{0i})	0.061***	
Linear Growth (r_{1i})	0.009***	
Quadratic Growth (r_{21})	0.000***	
Level 1 Error (e_{ti})	0.013	
Parameters (FIML)	7	
Deviance (FIML)	-329.241	

$*p < .05$. $**p < .01$. $***p < .001$.

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 9: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Sitting Postures

	Sit Supported		Infant Sustained Sit Supported		Sit Unsupported	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Intercept 6 months						
Intercept β_{00}	0.243	0.042	0.435***	0.065	0.282***	0.056
Male	0.011	0.051	0.120	0.067	0.067	0.057
HR-ND	0.089	0.057	-0.073	0.087	-0.123	0.073
HR-LD	0.175*	0.081	-0.123	0.089	-0.154*	0.081
HR-ASD	0.214*	0.087	-0.294**	0.090	-0.225**	0.071
Growth Rate						
Intercept β_{10}	-0.026	0.018	0.039	0.012	0.049	0.025
Male	-0.010	0.021	-0.009	0.012	-0.057*	0.026
HR-ND	-0.046	0.026	0.014	0.016	0.090*	0.037
HR-LD	-0.060	0.031	0.022	0.017	0.106**	0.036
HR-ASD	-0.065*	0.029	0.040*	0.017	0.120***	0.035
Acceleration/Deceleration						
Intercept β_{20}	0.002	0.002			-0.007*	0.003
Male	0.001	0.002			0.006*	0.003
HR-ND	0.004	0.003			-0.009*	0.004
HR-LD	0.006	0.003			-0.010*	0.004
HR-ASD	0.005	0.003			-0.010*	0.004
Variance Components						
Intercept (r_{0i})	0.037***		0.034***		0.031***	
Linear Growth (r_{1i})	0.004***		0.001**		0.006**	
Quadratic Growth (r_{21})	0.000*				0.000*	
Level 1 Error (e_{ti})	0.015		0.080		0.033	
Parameters (FIML)	7		4		7	
Deviance (FIML)	-318.121		246.047		-0.326	

*p < .05. **p < .01. ***p < .001.

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 10: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Al-4

	All-4	
	Coefficient	SE
Intercept 6 months		
Intercept β_{00}	0.029*	0.013
Male	0.004	0.015
HR-ND	0.034	0.022
HR-LD	-0.026	0.015
HR-ASD	-0.021	0.016
Growth Rate		
Intercept β_{10}	0.052**	0.009
Male	0.020*	0.009
HR-ND	-0.020	0.013
HR-LD	0.001	0.011
HR-ASD	-0.031**	0.011
Acceleration/Deceleration		
Intercept β_{20}	-0.006***	0.001
Male	-0.003*	0.001
HR-ND	0.003	0.002
HR-LD	0.001	0.001
HR-ASD	0.006***	0.002
Variance Components		
Intercept (r_{0i})	0.001	
Linear Growth (r_{1i})	0.000	
Quadratic Growth (r_{21})	0.000	
Level-1 Error (e_{ti})	0.006	
Parameters (FIML)	7	
Deviance (FIML)	-686.878	

Table 11: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Standing Postures

	Stand Supported		Infant Sustained Stand Supported		Stand Unsupported	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Intercept 6 months						
Intercept β_{00}	0.039***	0.010				
Male						
HR-ND						
HR-LD						
HR-ASD						
Growth Rate						
Intercept β_{10}	0.079***	0.017	0.203***	0.035	-0.019	0.006
Male	0.006	0.015	0.027	0.037	0.002	0.007
HR-ND	-0.032	0.022	-0.012	0.046	0.003	0.009
HR-LD	-0.048*	0.021	-0.047	0.045	0.003	0.009
HR-ASD	-0.065**	0.020	-0.147**	0.055	0.013	0.008
Acceleration/Deceleration						
Intercept β_{20}	-0.007	0.002	-0.012**	0.004	0.006	0.001
Male	-0.001	0.002	-0.002	0.005	-0.001	0.001
HR-ND	0.003	0.003	0.001	0.006	-0.001	0.002
HR-LD	0.005	0.003	0.004	0.006	-0.002	0.001
HR-ASD	0.007***	0.003	0.017*	0.007	-0.004	0.001
Variance Components						
Intercept (r_{0i})						
Linear Growth (r_{1i})	0.003***		0.014***		0.000***	
Quadratic Growth (r_{21})	0.000***		0.000***		0.000***	
Level-1 Error (e_{ti})	0.012		0.065		0.003	
Parameters (FIML)	4		4		4	
Deviance (FIML)	-419.798		195.698		-776.080	

*p < .05. **p < .01. ***p < .001.

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 12: Mean Rate per 10 Minutes (M), Standard Deviations (SD), and Ranges of Volubility and Syllabic Vocalizations at 6, 8, 10, 12 & 14 months by Outcome Group

	LR			HR-ND			HR-LD			HR-ASD		
	M	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*	*M*	*SD*	*Range*
6 Months												
Volubility	10.79	5.02	21.77	12.67	11.86	41.34	12.72	7.81	30.05	8.04	6.74	18.26
Syllabic Voc.	.40	1.30	6.37	1.34	3.35	14.00	.98	1.75	4.78	0.00	0.00	0.00
8 Months												
Volubility	15.37	8.40	32.40	20.18	11.91	47.93	23.21	18.90	71.44	15.04	9.14	26.84
Syllabic Voc.	3.62	4.72	18.80	4.58	3.51	12.96	3.70	6.84	25.03	3.57	3.70	9.73
10 Months												
Volubility	23.71	12.54	45.33	26.75	19.35	78.37	21.47	10.88	45.01	16.28	10.48	30.51
Syllabic Voc.	8.10	5.89	19.33	11.59	13.46	55.30	7.09	5.73	18.88	5.10	5.27	18.01
12 Months												
Volubility	28.17	17.43	66.75	28.65	12.26	42.70	30.20	16.99	56.00	16.78	10.71	31.88
Syllabic Voc.	9.17	5.82	20.39	12.74	9.44	32.38	12.80	9.50	29.21	5.90	5.98	20.00
14 Months												
Volubility	31.89	13.52	60.00	38.03	22.82	75.12	27.56	15.58	63.15	19.13	11.12	37.94
Syllabic Voc.	16.03	11.35	50.80	21.57	19.27	62.32	14.12	8.59	26.33	8.70	7.59	23.15

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorde

Table 13: Conditional Growth Models of Gender and Outcome Group Predicting Growth Trajectories for Total Vocalizations (Volubility) and Syllabic Vocalizations

	Volubility		Syllabic Vocalizations	
	Coefficient	SE	Coefficient	SE
Intercept 6 months				
Intercept β_{00}	12.690***	0.899		
Male				
HR-ND				
HR-LD				
HR-ASD				
Growth Rate				
Intercept β_{10}	2.394***	0.337	1.610***	0.099
Male	-0.902**	0.327	-0.2349	0.143
HR-ND	0.590	0.491	0.044	0.168
HR-LD	-0.102	0.411	0.031	0.174
HR-ASD	-1.410***	0.380	-0.159	0.187
Variance Components				
Intercept (r_{0i})				
Linear Growth (r_{1i})	1.378***		0.263***	
Level-1 Error (e_{ti})	154.010		23.217	
Parameters (FIML)	2		4	
Deviance (FIML)	3113.781		2438.204	

*$p < .05$. **$p < .01$. ***$p < .001$.

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 14: Descriptive Statistics for Total Vocalizations and Syllabic Vocalizations by Unsupported Sitting Status (Non-Sitters vs. Sitters) at 6 months: Percentage of Infants who Produced the Behavior (%), Median (Mdn), Average Deviation (AD), and Range

	LR		HR-ND		HR-LD		HR-ASD	
	Non-Sitters N = 11	Sitters N = 14	Non-Sitters N =11	Sitters N = 13	Non-Sitters N = 12	Sitters N = 3	Non-Sitters N = 8	Sitters N = 0
Total Vocs.								
%	100	100	100	100	100	100	100	-
Mdn	9.89	10.68	8.75	9.95	8.95	19.27	5.29	-
AD	2.59	4.06	4.09	7.64	4.24	7.74	5.61	-
Range	4.78-18.62	.51-22.28	2.79-19.62	.80-35.98	3.92-19.96	13.87-33.97	1.99-20.25	
Syllabic Vocs.								
%	0	43	18	40	25	67	0	
Mdn	0.00	0.00	0.00	0.00	0.00	0.38	0.00	-
AD	0.00	0.95	1.10	2.79	1.24	1.85	0.00	-
Range	.00-.00	.00-6.37	.00-6.72	.00-14	.00-4.78	.00-4.36	.00-.00	

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 15: Descriptive Statistics for Total Vocalizations by Posture Context (Lying vs. Sitting) at 6 months: Percentage of Infants who Produced the Behavior (%), Median (Mdn), Average Deviation (AD), and Range

	LR N=7		HR-ND N=10		HR-LD N=5		HR-ASD N=1	
	Lying	Sitting	Lying	Sitting	Lying	Sitting	Lying	Sitting
Total Vocs.								
%	86	50	80	70	100	60	100	0
Mdn	0.98	0.38	0.89	0.41	0.74	0.29	2.94	0.00
AD	0.87	0.56	0.79	0.61	0.55	1.04	-	-
Range	.00-2.81	.00-1.74	.00-3.73	.00-2.19	.54-2.41	.00-3.46	-	-

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

Table 16: Descriptive Statistics for Total Vocalizations and Syllabic Vocalizations by Posture Context (Lying vs. Sitting) at 8 months: Percentage of Infants who Produced the Behavior (%), Median (Mdn), Average Deviation (AD), and Range

	LR N=11		HR N=18		HR-LD N=7		HR-ASD N=6	
	Lying	Sitting	Lying	Sitting	Lying	Sitting	Lying	Sitting
Total Vocs.								
%	46	100	56	94	100	100	100	100
Mdn	0.00	0.78	1.12	1.92	2.86	2.4	0.25	1.86
AD	0.96	0.47	1.35	1.06	1.65	0.73	0.50	0.41
Range	.00-3.40	.13-1.84	.00-4.36	.00-5.05	.59-5.85	1.15-4.52	.00-1.53	1.08-2.63
Syllabic Vocs.								
%	14	86	54	92	60	100	50	75
Mdn	0.00	0.27	0.14	0.78	0.19	0.49	0.08	0.48
AD	0.02	0.18	0.87	0.53	0.76	0.17	0.14	0.43
Range	.00-.10	.00-.77	.00-3.12	.00-1.86	.00-1.73	.14-.63	.00-.38	.00-1.20

Note. HR-ND = High Risk-No Diagnosis; HR-LD = High Risk-Language Delay; HR-ASD = High Risk=Autism Spectrum Disorder

6.0 FIGURES

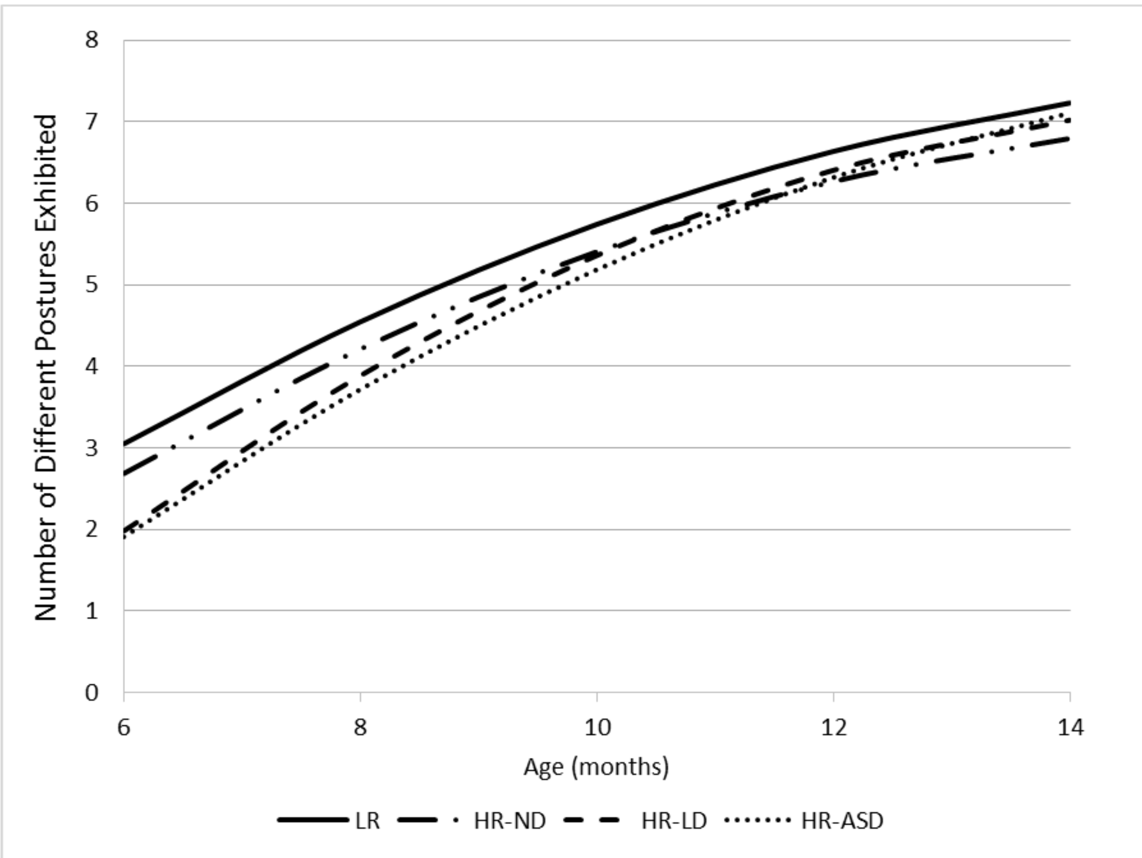


Figure 1: Developmental trajectories of Posture Repertoire by outcome group from 6 to 14 months of age

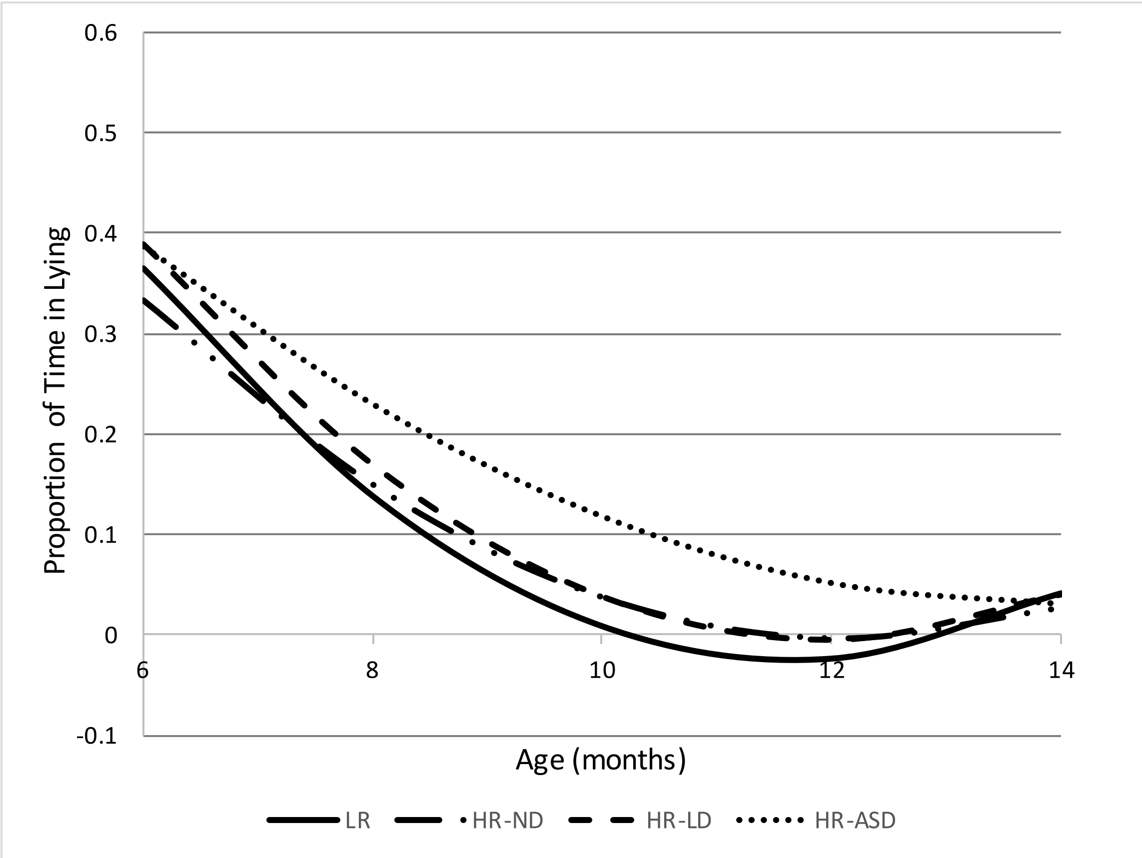


Figure 2: Developmental trajectories of Lying by outcome group from 6 to 14 months of age

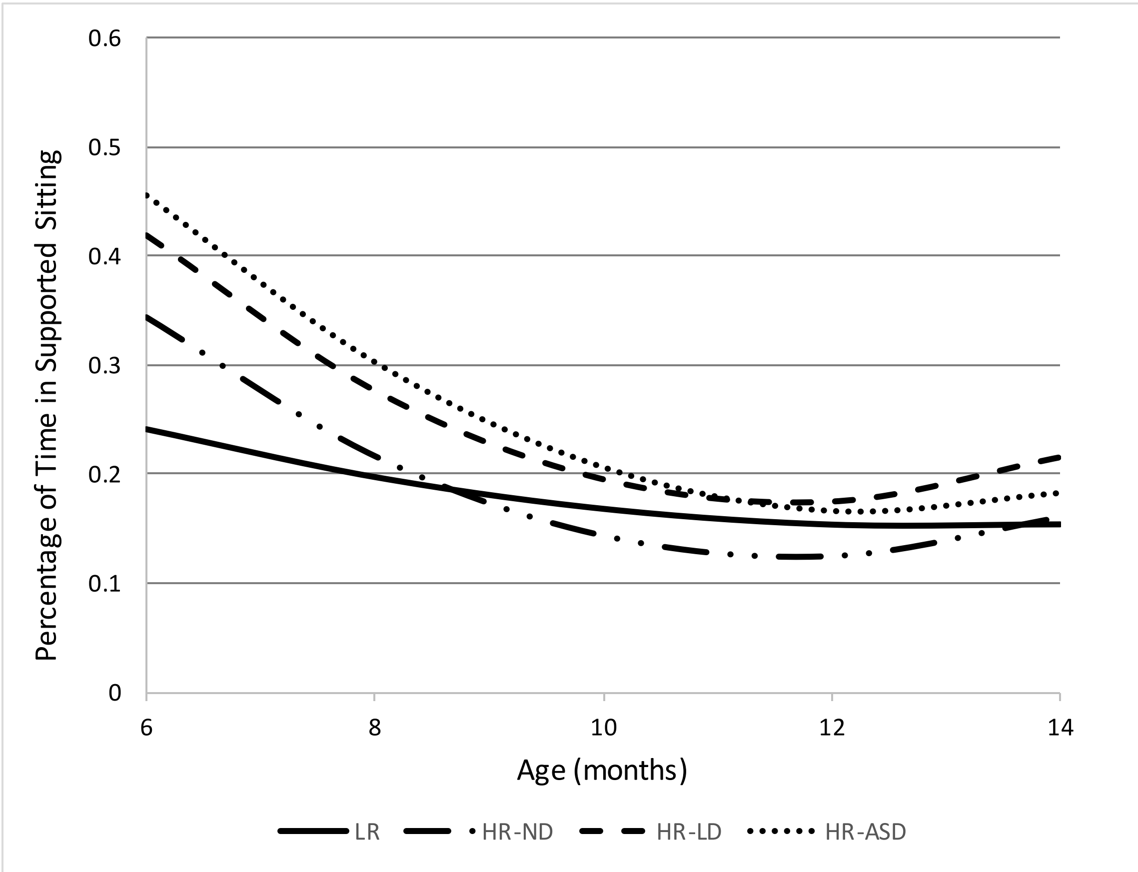


Figure 3: Developmental trajectories of Supported Sitting by outcome group from 6 to 14 months of age

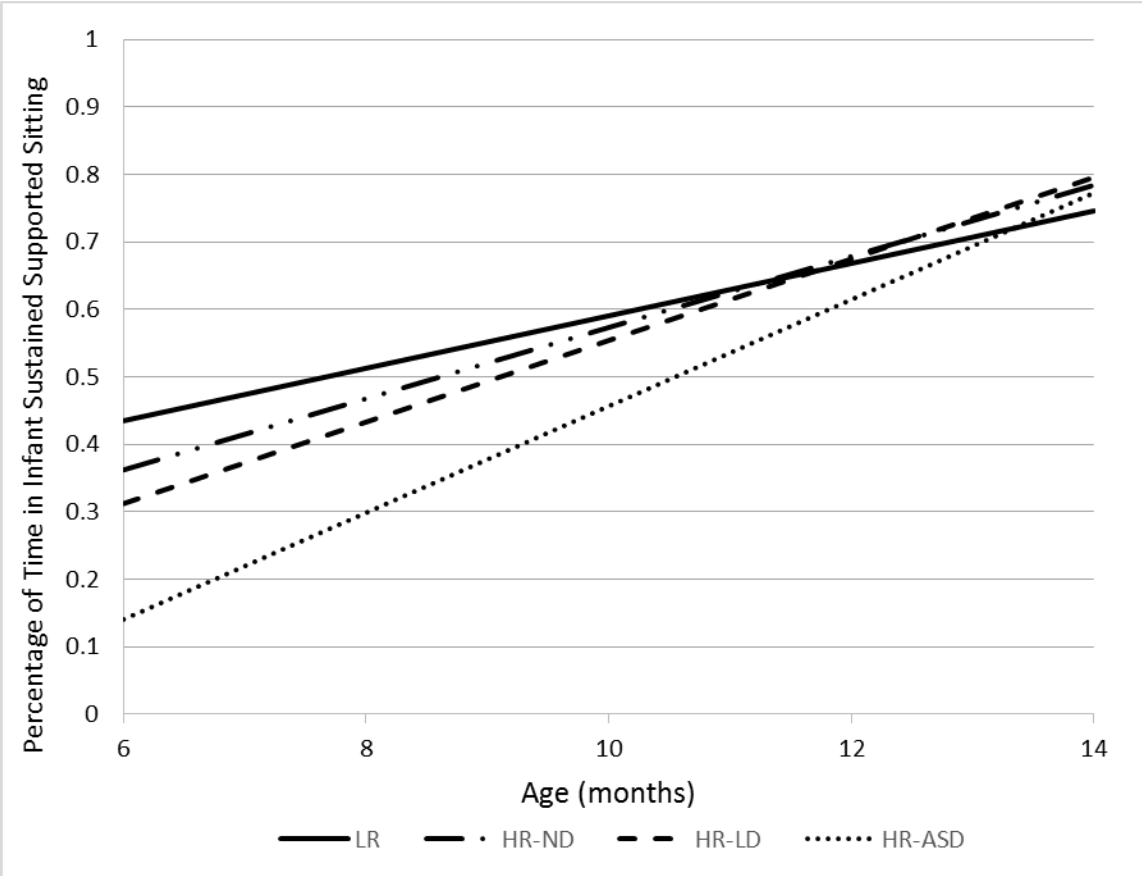


Figure 4: Developmental trajectories of Infant Sustained Supported Sitting by outcome group from 6 to 14 months of age

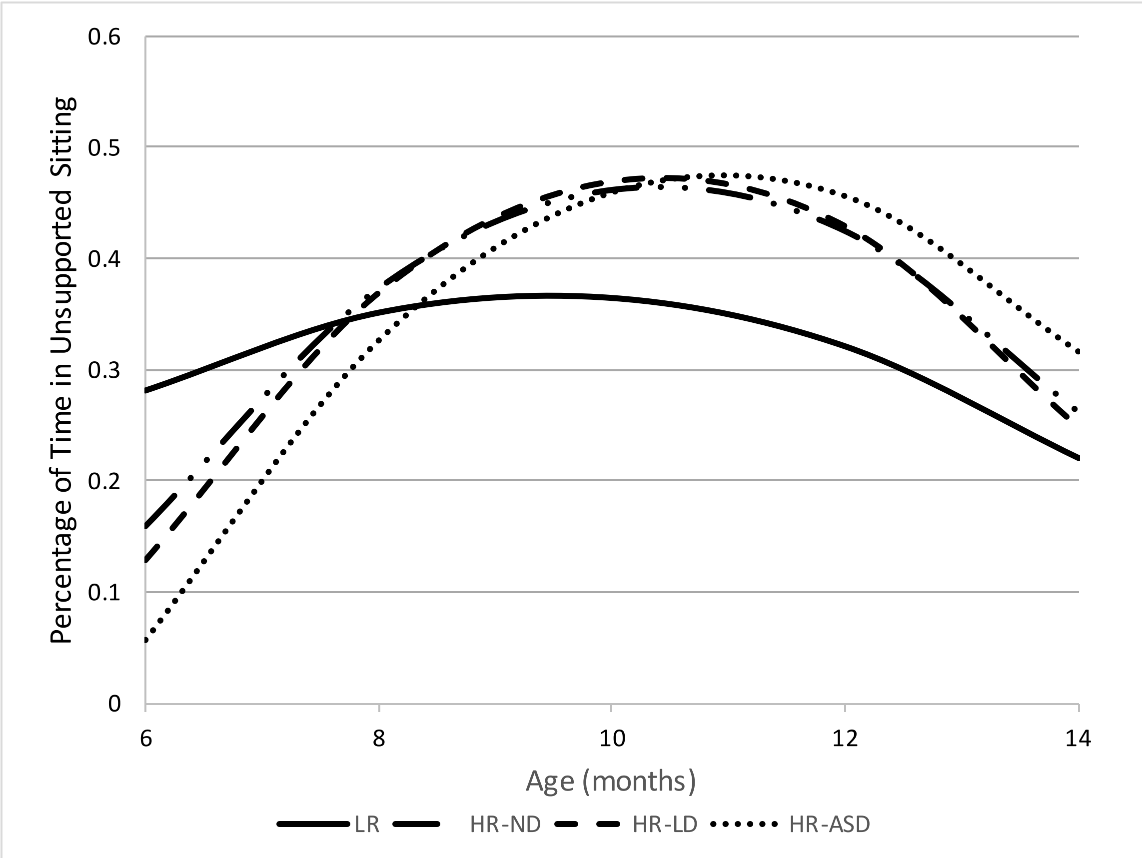


Figure 5: Developmental trajectories of Unsupported Sitting by outcome group from 6 to 14 months of age

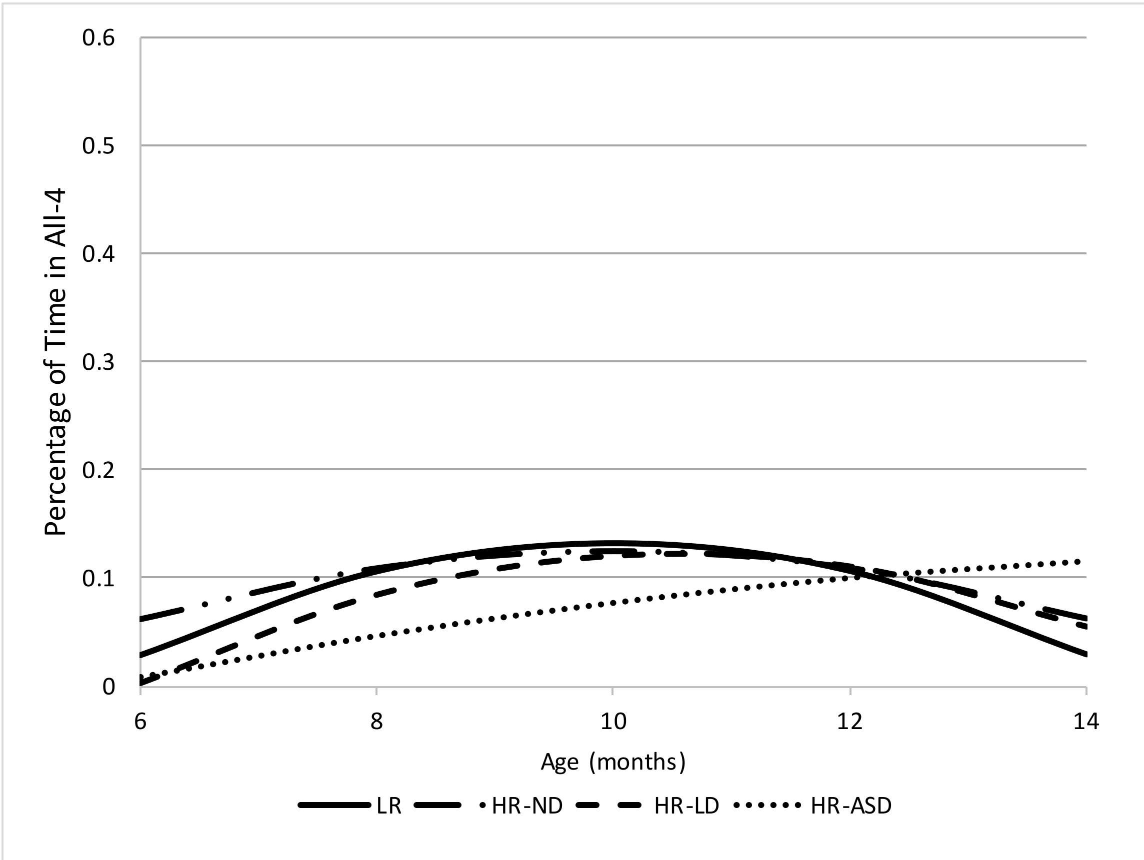


Figure 6: Developmental trajectories of All-4 by outcome group from 6 to 14 months of age

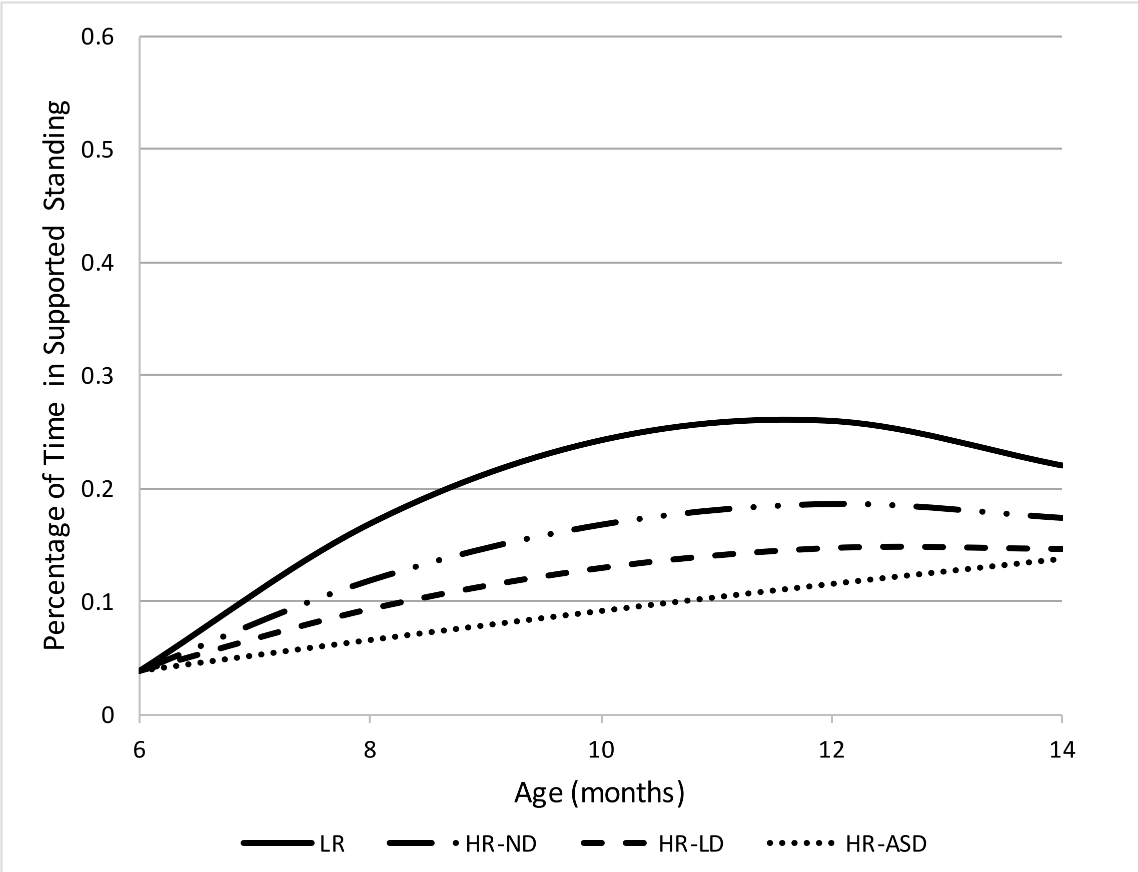


Figure 7: Developmental trajectories of Supported Standing by outcome group from 6 to 14 months of age

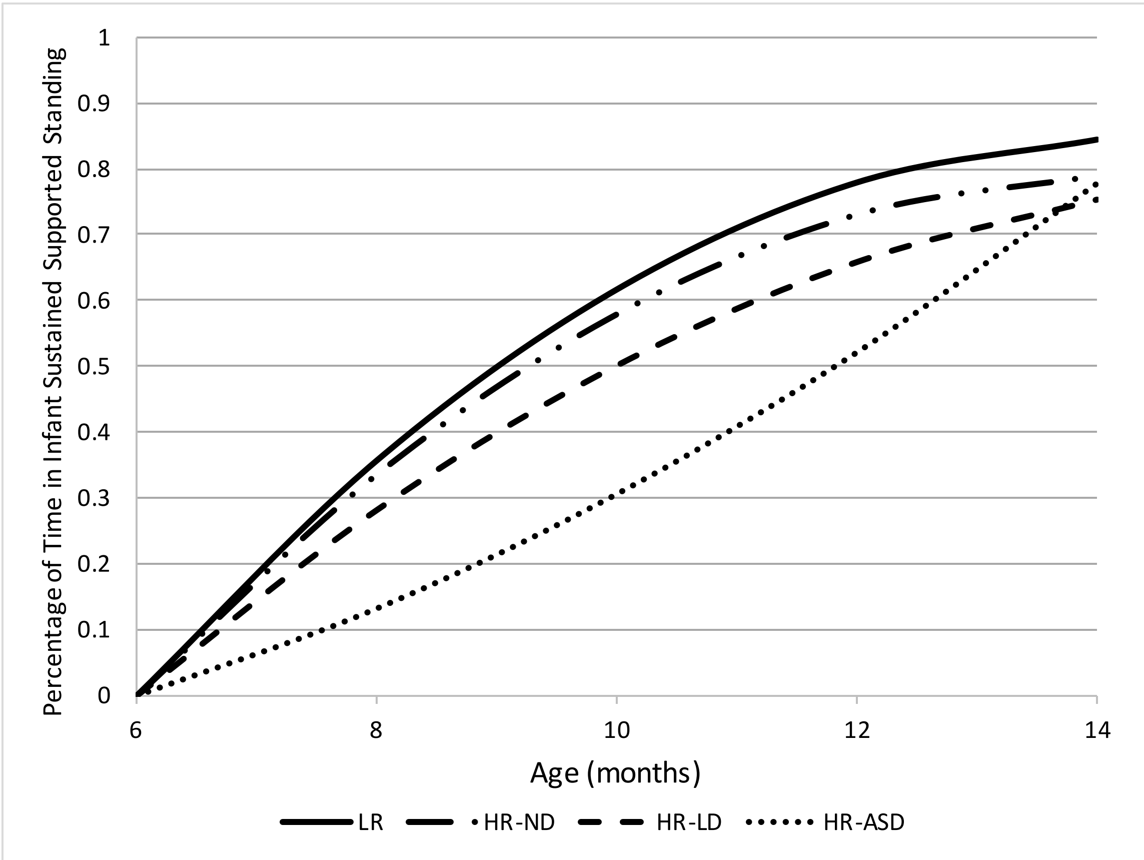


Figure 8: Developmental trajectories of Infant Sustained Supported Standing by outcome group from 6 to 14 months of age

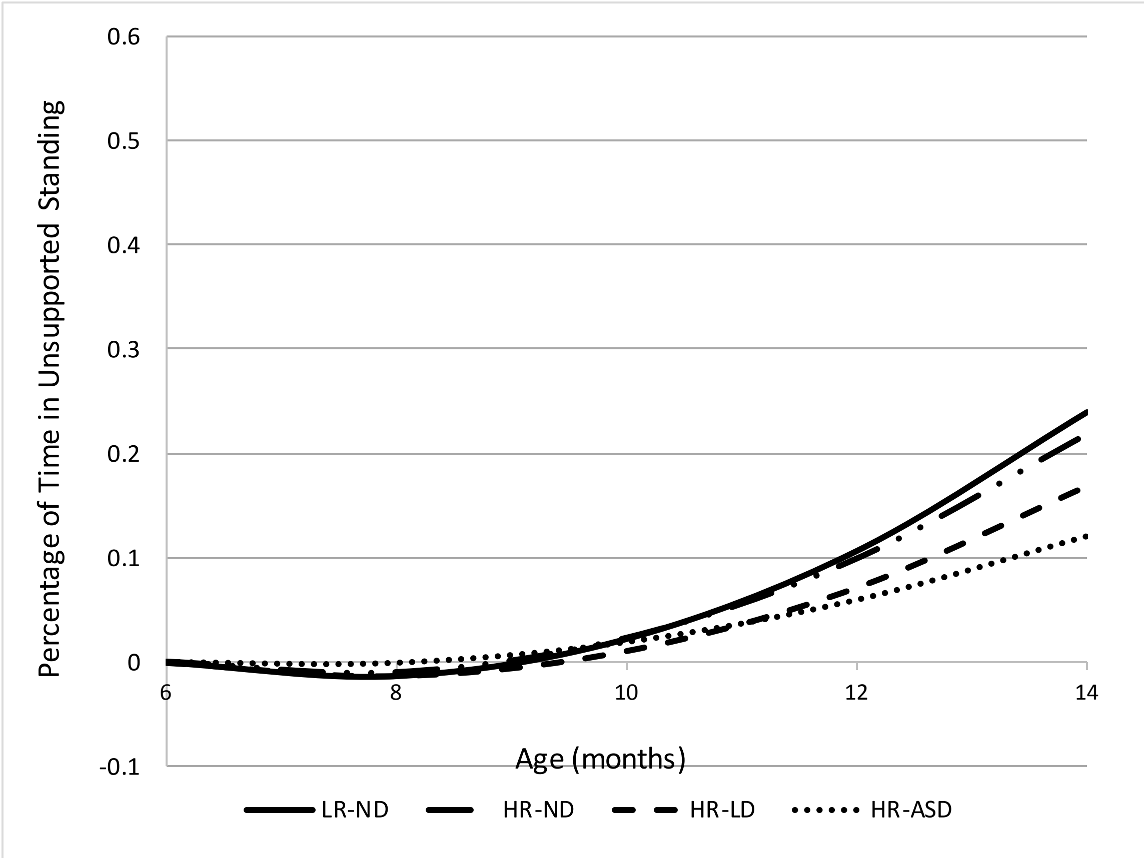


Figure 9: Developmental trajectories of Unsupported Standing by outcome group from 6 to 14 months of age

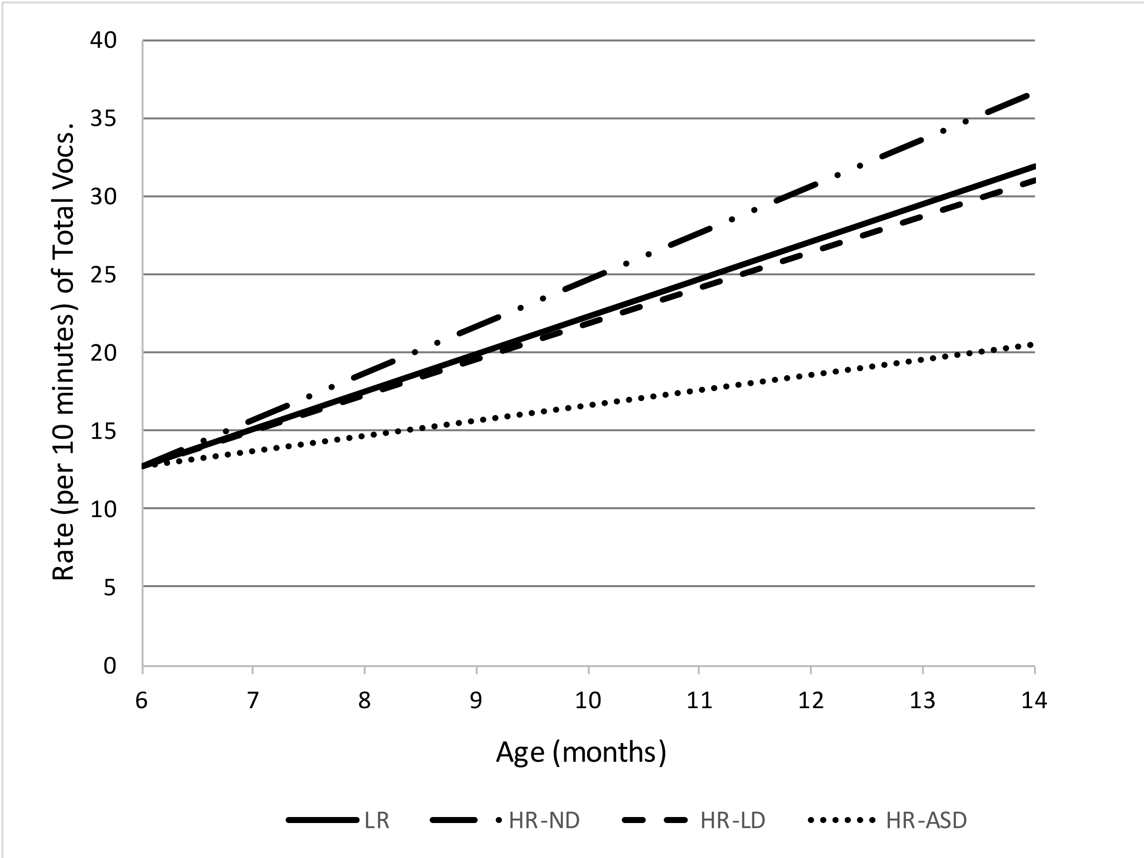


Figure 10: Developmental trajectories of Total Vocalizations (i.e., Volubility) by outcome group from 6 to 14 months of age

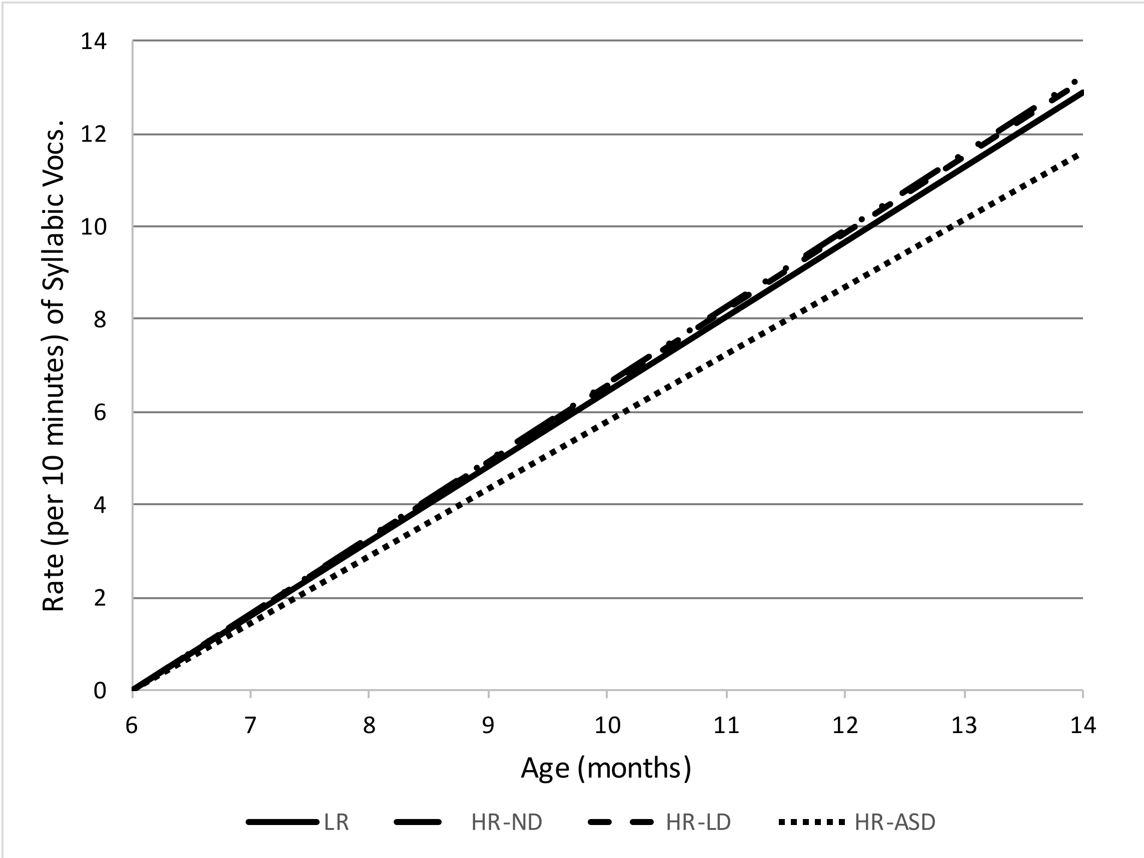


Figure 11: Developmental trajectories of Syllabic Vocalizations by outcome group from 6 to 14 months of age

APPENDIX A

SUMMARY OF REFERRALS, EVALUATIONS, AND SERVICES FOR HR INFANTS

Table 17 Summary of Referrals, Evaluations, and Early Intervention Services for HR infants

SN	Referral	Evaluation	Results	EI Services
HR-ASD				
12417	Contacted by research staff due to low scores on study measures	Yes – 22m	Diagnosed with PDD-NOS at 22m; referred for services	SLT, OT, and CD from 23m+
19521	Contacted by research staff due to low scores on study measures	Yes – 36m by study	Diagnosed with PDD-NOS by study but parent did not agree	N/A
19576	Contacted by research staff due to low scores on study measures	Yes – 36m by study	Diagnosed with PDD-NOS by study; parent scheduled hearing evaluation	N/A
17438	Contacted by research staff due to failed MCHAT at 24m	Yes – 26 and 30m	Diagnosed with Autism at 30m; referred for EI services	SLT, PT, and OT from 24m+
36575	Self-referred	Yes – 11m	Referred for EI services	PT and OT from 11m+
36578	Self-referred	Yes – 10m	Referred for EI services	OT, SLT, PT, and CD from 11m+
36579	Self-referred	Yes – 10m	Referred for EI services	OT and CD from 12m+
24909	Self-referred (also failed MCHAT at 24m)	Yes – 16m	Diagnosed with Expressive/ Receptive Language Disorder; referred for EI services	CD, EI preschool, play group from 24m+
16694	Self-referred (also failed MCHAT at 24m)	Yes- 18, 24, and 36m	Diagnosed with PDD-NOS at 24m and Autism at 36m; referred for EI services	OT, SLT, and CD from 18m+
44093	Contacted by research staff due to low scores on study measures	Yes- 19 and 26m	Diagnosed with ASD at 24m by study; had follow up evaluation at Children's Hospital at 26m and diagnosis was confirmed	SLT and CD from 20m+
45482	Self-referred for PT evaluation at 10 months; Contacted by research staff at 36 months due to elevated ADOS	Yes-36m by study	Diagnosed with ASD at 36m by study; referred for services	PT 11-18m
58228	Contacted by research staff due to low scores on study measures	Yes- 18, 24, and 36m	Diagnosed with Autism at 18m by study; referred for services	OT, SLT, and CD from 22m+
56524	Contacted by research staff due to high scores on ADOS at 24m	Yes-24m by study and 26m	Diagnosed with ASD by study at 24 m.; referred for EI	SLT and CD 27m+

SN	Referral	Evaluation	Results	EI Services
HR-LD				
24843	Initiated by study due to poor articulation at 36m	Unknown	Unknown	SLT (for articulation) from 18-36m^{+}
16640	Initiated by study due to high (invalid) ADOS and language difficulties at 36m	Unknown	Unknown	N/A
26375	Initiated by study due to low CDI and/or MSEL scores at 24m	No – parent reported language improvement	N/A	N/A
23494	Initiated by study due to low CDI and/or MSEL scores at 24m	No	N/A	PT from 20m
15000	Self-referred	Yes – S/L evaluation at 20m	Diagnosed with Expressive/ Receptive Language Disorder; referred for services	SLT and CD from 20-36m
59423	Self-referred	Yes – 16m	Diagnosed with speech apraxia; referred for EI services	SLT from 16-33m
17811	Self-referred	Yes – 9m	Referred for EI services	SLT from 9-18m
25042	Self-referred	Yes – 18m	Referred for EI services	SLT, OT, PT, and CD from 18-24m
21717	Self-referred	Yes – 18m	Referred for EI services	SLT and CD from 18-24m
61218	Self-referred	Yes – 30m	Results within normal limits	N/A
12665	No	N/A	N/A	N/A
13856	No	N/A	N/A	N/A
14578	No	N/A	N/A	N/A
27175	Initiated by parent due to concerns about language; offered a referral to Duquesne clinic but parent declined	No	N/A	N/A
36748	No	N/A	N/A	N/A
50434	Self-referred	Yes-S/L and OT evaluation at 15m	Diagnosed with Expressive/Receptive Language Disorder referred for services	SLT and CD from 16m+

SN	Referral	Evaluation	Results	EI Services
HR-ND				
15495	Self-referred	Yes – 13m	Gross motor delays	PT from 13-36m
18445	Self-referred	Yes – 13m	Gross motor delays	PT from 13-14m
23958	Self-referred	Yes – 10m	Feeding difficulties	CD and feeding from 10m
34056	Self-referred	Yes – 10m	Global delays	OT, PT, and SLT from 11m
38940	Self-referred	Yes – 30m for tantrums	Results within normal limits	N/A
35548	Self-referred	Yes – 30m for stuttering	Results within normal limits	N/A

Note. EI = Early Intervention; HR-ASD = High Risk-Autism Spectrum Disorder; PDD-NOS = Pervasive Developmental Disorder-Not Otherwise Specified; SLT = Speech and Language Therapy; OT= Occupational Therapy; CD = Child Development Therapy; MCHAT = Modified Checklist for Autism in Toddlers; PT = Physical Therapy; HR-LD = High Risk-Language Delay; ADOS = Autism Diagnostic Observation Schedule; CDI = MacArthur-Bates Communicative Development Inventory; MSEL = Mullen Scales of Early Learning; S/L = Speech and Language; HR-ND = High Risk-No Diagnosis.

APPENDIX B

BEHAVIORAL CODING DESCRIPTIONS

Posture Coding

Code all postural changes that occur during the session EXCEPT posture transitions. Transitions are defined as:

1) The child stays in a posture for less than one second.
   - Example: If the child is sitting in the parent's lap and the parent picks her up and moves her into a supported stand, do not code the Held in between the Sit Supported and the Stand Supported if it lasts for less than 1 sec.

2) The child is in a posture for more than 1 sec.**,** but is transitioning to another posture**.**
   - In these instances the child *must remain in constant motion* throughout the transition.
   - This also applies to instances in which the parent picks up the child and moves him/her to a new location, but the parent's arms remain in constant motion while moving the child (i.e., constant movement between the old and new locations).

Note: As a general rule, the transition process could take up to almost 2 seconds. However, if it ever goes beyond that mark, it is most likely not a transition. If it's getting close to two seconds, take a good look before you decide to call it a transition.

Main Posture Types

HELD: The child is held or carried in another person's arms with his/her feet off the floor or surface. This does not include a child sitting in the parent's lap.

PRONE: Lying on the stomach. The child should have more than half (vertical chest line) of the stomach in contact with a surface (includes a child lying on his/her stomach and propped up on hands or elbows). For a child to be in a prone position, some part of his/her hip(s) *must* be in contact with the surface.

SUPINE: Lying on the back or the side on a relatively horizontal/flat supportive surface. If the child is on his or her side, one or both hips must be in contact with a supportive surface.

- When deciding between supine and prone, if the angle of the child's chest relative to the surface below is *more than 45 degrees,* the posture is supine

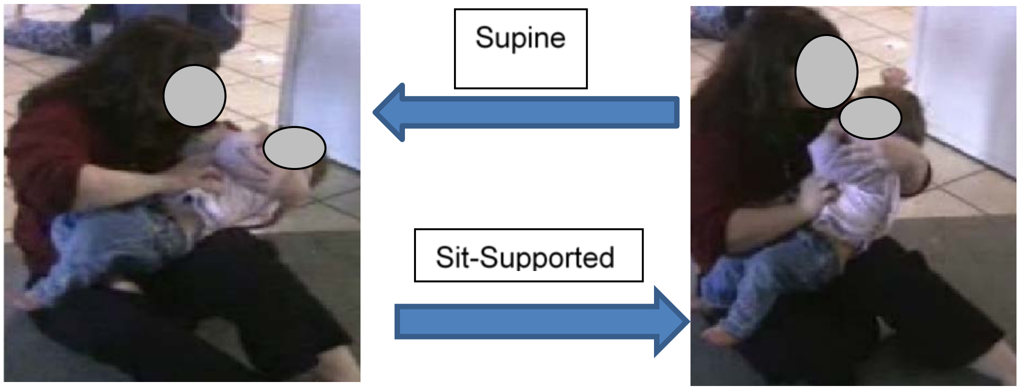
Supine

Lying on side on a supportive surface. Hip is in contact with surface. Angle of torso relative to surface below is more than 45 degrees.

Prone

Lying on side/stomach. Hip is in contact with the surface. Angle of torso relative to surface below is less than 45 degrees.

- When deciding between supine and sitting, if the angle of the child's back is *less than 45 degrees*, the posture is supine.



SITTING: In general, Sit is distinguished from Supine by the angle of the torso relative to the floor. If the angle of the child's torso relative to the floor is *greater than* 45 degrees, code the posture as Sit. Next, determine whether sitting is Supported or Unsupported

SIT SUPPORTED should be coded if *any* of the following criteria are met:

1) Child Sustainment: The child is supported by one or both hands placed on a firm surface (not including her own body).

2) Other Sustainment: The child is propped in a sitting position with a pillow or very large stuffed toy or is seated on furniture that affords a sitting position.

3) Caregiver Sustainment: The child is sitting on the parent's lap, or the parent provides *firm and visible support* by holding the child around the middle, by holding the child's hands, or by placing their hands under the child's buttocks for at least one second. Instances where the child puts her hands on the parent's leg and there is no other support from the parent code as infant sustainment.

4) Furniture Contained: The child is in a piece of child furniture that affords a sitting position.

SIT UNSUPPORTED should be coded if *any* of the following criteria are met:

1) The child's back is generally straight.

2) The child is not propped in a sitting position by a pillow etc. There may be occasional contact with other surfaces, but the contact is not propping the child in a sitting position.

3) The child's hand/s are generally free to move and manipulate toys. The hand/s may make brief contact with other surfaces, but the contact lasts for less than 5 seconds. If the child is sitting and learning with the hands resting on the legs, code as Sit Unsupported.

KNEEL: On one or both knees, with arms and hands free to move. The child may be upright or sitting back on his/her feet or heels. The hands, back, and/or torso cannot use the floor or any other firm surface as a support. If the child's bottom comes into contact with the floor or another surface other than the legs, feet, or heels code as a sit unsupported.

All 4: On hands and knees (similar to a crawling position) or other 4-point contact, such as both feet and both hands on the floor, or one knee, one foot, and both hands on the floor. The hips cannot be in contact with the surface although the belly may be touching the support surface.

- Instances in which the child has his or her feet and hands on a surface, with torso at a 90 degree angle or less relative to the legs code as All-4. However, if the angle exceeds 90 degrees, then the posture is coded as a Stand Supported.

All 4
Both hands and feet are down. Angle of torso is less than 90 degrees so it can't be stand supported. Knees are bent at an angle greater than 90 degrees so it can't be a squat.

STANDING: To qualify as a Stand, at least one of the child's feet must be firmly on the floor or surface (e.g., couch or mom's lap), and the torso and knees must be at an angle greater than 90 degrees. Next determine whether the Stand is Supported or Unsupported.

STAND SUPPORTED should be coded if *any* of the following criteria are met:

1) Child Sustainment: The child is standing supported by one or both hands placed on a firm surface.

2) Other Sustainment: The child is leaning on a wall or piece of furniture that is providing support.

3) Caregiver Sustainment: The child is supported in a standing position by a parent, who is *actively holding* the child around the middle, under the arms, under the butt, or by the hand(s) *for at least one second*.

4) Furniture Contained: The child is in a piece of child furniture that affords a standing position.

STAND UNSUPPORTED should be coded if *any* of the following criteria are met:

1) The child is not supported in a standing position by child furniture or a parent. There may be occasional contact with other surfaces (e.g., touches by a parent, toys), but the contact is not constant (lasting more than one second) or providing consistent support

2) The child's arms and hand(s) are generally free to move and manipulate toys. The back or torso is also not in contact with a surface. There may be brief body contact with surfaces, but the contact lasts for less than 5 seconds.

SQUAT: The child's feet are on the floor, with *knees bent at an angle of 90 degrees or less*. The child *may or may not* be supported by his/her own hands, the hands of the adult, or by leaning the torso front or back against a firm surface. The key here is that the buttocks and/or knees are not in contact with the floor.

Squat
Feet are on the floor and the knees are bent at an angle of 90 degrees or less. Knees and buttocks are not in contact with the floor.

Stand
Infant is now in a stand because the knees are bent at an angle greater than 90 degrees.

Vocalization Coding

- Only code vocalizations that are spontaneous (i.e., not explicitly elicited) and are clearly codable. Elicited vocalizations are those in which a) the child is given explicit instructions that involve a specific directive. (e.g., mother says "say baby" and the child says "baby.")

- Do not code any vegetative sounds that are produced without additional speech sounds. Vegetative sounds include growl, burp, hiccup, cough/sneeze, gurgle, snorting, swallowing, and deep breathing.

- Do not code instances of laughing, squealing, fussing, whining, or crying.

- Vocalizations can occur in whisper form. These vocalizations should be coded. Do not confuse deep breaths with whispers. Deep breaths are *not* coded.

- For a vocalization bout to end, the baby must either stop vocalizing for at least 1 second or take a breath. Some babies pause in between their vocalizations without taking a breath in between. In these instances, if the pause is less than 1 seconds, code all sounds produced as 1 vocalization.

- Inhaled breath should never be counted as a vocalization and should always signify a break in vocalization bout.

NON-WORD VOCALIZATIONS

- Non-word vocalizations are any voluntary, uninterpretable sound the infant makes. Non-word vocalizations included vowel strings (e.g., [eeaa]), reduplicated babbling (e.g., [gaga]), and variegated babbling (e.g., [bama]).

WORDS

- Use of the same sound pattern to refer to a specific referent on multiple occasions or in different contexts.

- They are either actual English words (e.g., "dog," "baby," "hot"), verbal markers such as "uh huh" (yes) or "uh oh," or sound patterns that are consistently used to refer to a specific object or event (e.g., "bah" for bottle in a variety of contexts).

SYLLABIC VOCALIZATIONS

- Once you have coded a vocalization, the next step is to determine whether or not it contains at least one consonant vowel (CV) syllable unit (in either order)

- Can be produced at a relatively quick, crisp speed from the consonant to the vowel (e.g., [ba], or [la]) and sound similar to adult-like speech; or the transition from the consonant to the vowel can be slow, may sound poorly articulated and unlike adult speech (e.g. [bbbbbbb][aaaaaa]).

- Includes variegated babbling, or two or more different consonant-vowel (CV) units that occur within one breath (e.g., [ba][ba][da][da], [la][de], [gu][gu][da][da], or [ba][be]), and canonical or reduplicated babbling, or the reproduction of the same CV unit two or more times (e.g., [ba][ba], or [ad][ad]).

- "Y" sounds are considered consonants so treat them as such when you code (e.g., [oy]).
- "W" sounds are also considered consonants but it must be a strong "w" sound and not the sound that is made from changing from an "oh" to an "ah" sound.
- If an "h" sound occurs in between a set of vowels, code the "h" sound like a consonant (e.g., [aha]).

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